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CONTENTS

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GROUND PLAN OF A DYNAMIC METEOROLOGY

By HURD C. WILLETT

[Woods Hole Oceanographic Institution, Woods Hole, Mass., July 10, 1931]

This is a summary of a discussion recently presented at a meeting of the New England branch of the American Meteorological Society held at the Massachusetts Institute of Technology in Cambridge.

The discussion was based on T. Bergeron's recent paper "Richtlinien einer dynamischen Klimatologie," appearing in Meteorologische Zeitschrift for July, 1930. This discussion is not limited strictly to the contents of Bergeron's paper, therefore statements made here are to be attributed directly to Bergeron only when that is specifically stated.

Bergeron's excellent effort toward a rationalization of the fundamental facts of climatology is particularly significant in two respects: (1) He has suggested a new and promising method of approach to the whole problem of the representation and explanation of climate, and (2) he offers for the first time practical suggestions as to how to introduce into statistical climatology some of the concepts, in modified form, which in recent years have been developed in connection with the analysis of synoptic weather maps.

Bergeron's main thesis may be stated somewhat as follows: Hitherto climatology has been essentially the systematic compiling of statistics on the individual meteorological elements, without much organized attempt to get at the underlying dynamic or thermodynamic phenomena in their entirety. We have complete charts of the distribution of atmospheric pressure, rainfall, temperature, wind, cloudiness, etc., but usually very little idea of just how the distributions of these elements tie up with one another, or just what sort of atmospheric activity, in toto, is behind these observed distributions. Bergeron points out, however, that this is by no means always the case. For example, in the more regular circulations of the subtropics, such as the trade wind systems, it is possible even from our present types of climatological charts to draw conclusions as to the thermodynamic basis of the observed atmospheric activity. Especially clearly marked are the more effective orographical influences in such regions. The more regular monsoon systems furnish another instance of a type of circulation which so definitely controls the climate of certain regions that it may be described completely in terms of a single atmospheric phenomenon. The best illustration of this is the Indian monsoon, where the underlying thermodynamic process is so well understood that it is necessary only to characterize a given period as one of weak or strong monsoonal activity in order to convey a comprehensive picture of the climate or climatic changes during the time in question. Here again orographical effects are readily recognized. But in general over the greater part of the temperate and northerly latitudes climatology offers no unifying picture of the prime thermodynamic forces controlling the climate. This is what a dynamic climatology should do. Therefore Bergeron undertakes to show how the concepts of air masses and fronts may be modified to furnish a key to the development of a comprehensive dynamic climatology.

If we look at almost any synoptic chart which covers a considerable area on the earth's surface, one of the things that stands out most strikingly is the existence of large scale air currents or large bodies of air at rest in which the meteorological elements are distinctly uniform in their horizontal distribution. Such extensive bodies of air which approximate a state of horizontal homogeneity in their properties we refer to as air masses. Their occurrence is due essentially to two facts. These are (1) the existence of extensive sources, or regions on the earth's surface where conditions are so uniform that the overlying atmosphere acquires horizontal homogeneity in its properties. Examples of such sources are the Arctic ice fields, snow-covered northerly continents in winter, the warm subtropical oceans, and continents, especially southerly or semiarid regions in summer; (2) the occurrence in the general circulation between subtropical and subpolar regions of large scale atmospheric movements. This makes possible large displacements of air masses from their sources with a considerable degree of conservation of certain of their characteristic properties, rather than the rapid turbulent mixing and loss of air mass characteristics which would occur if the latitudinal transport of air took place in small, disordered currents instead of in the large branches observed in such circulations.

Evidently if the existence of air masses of more or less definite characteristic properties be accepted, then their classification according to their characteristic properties and their detection on the synoptic chart become a material aid to weather forecasting. Bergeron has indicated further a classification of air masses which may be made a material aid to the understanding of climate. According to him there are two distinct methods of procedure in classifying air masses, each with its particular advantages.

(1) *The integral method.*—This method consists in picking out the most conservative or nonvariable properties of an air mass, such as the potential temperature or specific humidity, and using the characteristic seasonal values of these quantities for the classification and identification of the air masses appearing on the synoptic chart for a given region. Since the characteristic values of these conservative properties of air masses depend upon both the properties of the mass at its source and the sum total (integral) of the modifying influences to which the mass has been subjected in following its path from the source, it is evident that this method of classi-

fication can be used to advantage only at stations where a series of carefully analyzed synoptic charts based on observational material from a considerable area are prepared, for the complete life history of the air mass must be known. This follows from the fact that it is possible for two quite different air masses which have followed widely separated trajectories to arrive at the same point with approximate similarity of their conservative properties at the ground, yet with very significant differences in their vertical structure. At a forecast center where observational material from a wide network of stations is at hand, this system of air-mass classification is most advantageous, because the characteristic air masses for any given locality depend definitely upon the usual air mass sources and trajectories in that region. When the forecaster becomes familiar with these, he knows in detail the characteristics and therefore the type of weather to be expected locally with each particular air mass. On the other hand, because air masses classified in this way are essentially particular rather than general in nature, i. e., are dependent on local or regional geography, they are useless to the climatologist, who must have a perfectly general classification applicable anywhere on the earth's surface.

(2) *The differential method*.—This method consists in picking out the most variable or non-conservative properties of the air mass, in particular the lapse rate at lower levels and making the changes (differences) in the air mass properties effected by its most recent history, as indicated by the lapse rate, the basis for the air mass classification. On this principle all air masses may be grouped in the following four perfectly general classes:

(*a*) Warm: Air masses warmer than the surfaces over which they are moving, hence with a tendency toward increasing stability and stratification.

(*b*) Cold: Air masses colder than the surfaces over which they are moving, hence with a tendency toward increasing lapse rate and specific humidity.

(*c*) Indifferent: Air masses at the same temperature as the surfaces above which they occur.

(*d*) Unknown: Air masses whose temperatures relative to the underlying surfaces are unknown.

Classes (*a*) and (*b*) are the really important ones for this discussion; (*c*) applies primarily to air masses at their sources, or at least only to stagnant synoptic situations; (*d*) is of little significance, for as we shall see presently the properties of warm and cold masses are so distinctive that an experienced observer can readily detect them without the aid of any instrumental observations.

Although this classification of air masses might not be of as much assistance to the weather forecaster as the first method outlined above, it has the following definite advantages, in particular for the climatologist:

(1) It is perfectly general, applying equally well in polar and equatorial regions. It must be emphasized that the warm and cold designations indicate nothing about the actual temperature of the air mass itself, but only its temperature relative to the underlying surface. In fact, it is readily seen that cold air masses will tend to predominate at low latitudes, warm air masses at high latitudes. Furthermore, the transition from a warm to a cold or a cold to a warm air mass can take place very suddenly, and is especially likely to happen in summer and winter with the movement of air from land to water or vice versa. It will be found that such a change is followed by a very rapid adjustment of the characteristic properties of each mass, as outlined below, to those required for its new classification, at least at lower levels. A variable life history of the mass will be indicated by variable characteristics at different levels, the older influences appearing at the upper levels.

(2) The detection of the warm and cold mass differences is so easy to make that an experienced observer can usually classify the prevailing type of air mass without the aid of instruments or synoptic chart. The properties to be noted and the differences characteristic of warm and cold masses, according to Bergeron may be summed up briefly as follows:

(*a*) Lapse rate: The cold mass will have a steep lapse rate (equal to or greater than the saturation adiabatic), and the warm mass a stable lapse rate, probably well-marked stratification, and often even inversions in the actual temperature lapse rate. Although the direct measurement of the lapse rate requires instrumental observations at the ground and in the free air, a reliable qualitative estimate of the steepness of the lapse rate may be made by direct observation of properties (*b*), (*c*), (*d*), and (*e*) below.

(*b*) Turbulence: Because atmospheric stability tends to damp out the eddy energy of mechanical turbulence and to prevent convective turbulence, it follows that the winds in warm air masses are much less gusty than in cold masses. This difference is so marked that it is readily detectable by any trained observer, and is quite striking in anemograph records. Bergeron has found in one clearly marked transition from a typical warm mass to a typical cold mass that although the prevailing wind velocity was reduced by one-half, the absolute magnitude of the variations in wind velocity due to gustiness remained practically unchanged.

(*c*) Horizontal visibility: Since a steep lapse rate favors convective turbulence and the upward spread of mechanical turbulence, it tends to effect a uniform distribution throughout the atmosphere of both moisture and the solid impurities, dust, and smoke. Therefore in warm air masses the obscuring dust and smoke are kept at low levels, particularly below any marked inversions. Consequently inversions result in haze and smoke layers sharply bounded at their upper edge. And in general, in warm masses visibilities are markedly poor at low levels, markedly good at upper levels, whereas in cold masses just the reverse is true.

(*d*) Cloud forms: The effect of dust on horizontal visibilities in warm and cold air masses is accentuated by the typical condensation forms. Since the same distribution of water vapor as of dry dust is typical of warm and cold air masses, it follows that in warm-air masses condensation tends to take place at low levels, resulting characteristically in either surface fog or a low thick stratus deck. In cold-air masses, on the other hand, the moisture is carried up to cooler levels by convective turbulence, the condensation occurring aloft as cumulus or cumulo-nimbus clouds, usually only a broken cloud with excellent visibilities below.

(*e*) Precipitation forms: Evidently the typical form of precipitation in the warm-air mass, if any occurs, will be of the mist or drizzle type, from a low stratus or nimbus, and rather small in amount. In the cold-air mass the typical form will be the instability shower, of short duration, but frequently heavy. Hail and thunderstorms will belong to this type. All the typical warm and cold air mass characteristic condensation forms will be more in evidence and more nearly complete in the case of maritime than of continental air masses, due to the greater moisture content of the former. The differences in precipitation forms in these two air masses become particularly significant in the case of steady air movement

on a high coast line or against any marked orographical barrier. In the case of the stable warm-air mass the tendency is to a continued stratified air flow which will resist vertical displacement and seek the easiest way around rather than over the obstacle. Hence the warm air drizzle rain is comparatively little intensified by orographical influences. On the other hand, in the unstable or conditionally unstable cold mass such an obstacle furnishes just the needed initial impulse to start extensive overturning of the atmosphere. Therefore, on the windward side of orographical barriers the cold-air mass may be expected to deposit copious precipitation in an almost unbroken sequence of heavy showers.

From the above considerations it is evident to what a large extent the commonly observed meteorological elements, visibility, gustiness, cloud forms, and type and amount of precipitation depend upon the prevalence of the warm or cold air mass type. And since climate is only the integral over a period of time of the daily weather, it is obvious that the predominance of one or the other of these air mass types will be a controlling factor in the climate, and will in itself serve to a considerable degree to classify and explain the climate. Therefore Bergeron concludes that the first thing to be done to develop a dynamic climatology is to record regularly by direct observation the prevailing air mass type at all stations whose records are to be used for climatological purposes, just as is done with any meteorological element. A trained observer could do this with little difficulty.

But this is only half the picture. It remains to take into account the irregular variations that go with migratory cyclones and anticyclones, and these tie up with the problem of the genesis and displacement of fronts. Quite as important as the characteristic weather phenomena belonging to each of the air mass types, are the phenomena which occur at the boundaries or fronts between air masses. Charts showing the mean pressure distribution over the northern or southern hemisphere for a given month, or maps of the prevailing winds such as those of Köppen, indicate clearly the tendency to the existence of more or less permanent regions of seasonal high and low pressure which dominate the mean air movement over the greater portion of the earth's surface. Such semipermanent areas of high and low pressure are sometimes referred to as "centers of action", for they are the fundamental thermodynamic units controlling the general circulation. Their essential cause is found in the thermal differences existing in the troposphere over large areas following the establishment of convective or radiation equilibrium in response to differences in the earth's surface. Examples of well-marked centers of action are the Aleutian and Icelandic lows and the north continental highs in winter, and the Azores and Pacific highs which are best developed in summer. It is the existence of these centers of action that is responsible for the large branches in the general circulation which enable us to speak of extensive air masses with characteristic properties. A chart of prevailing winds will show furthermore that there are certain regions where air currents or air masses of widely different origin and properties tend to be brought into more or less direct opposition. Such opposing trends in the movement of air masses of northerly and southerly origin evidently tend to greatly intensify, locally, the normal poleward temperature gradient, that is, they constitute a region of marked front formation, or what Bergeron calls frontogenesis. Correspondingly there are also regions of marked divergence or dissipation of the horizontal temperature differences, a process which Bergeron calls frontolysis. These two processes are particularly important because they largely determine the activity of the migratory cyclones and anticyclones. It must be emphasized, however, that on any particular occasion the actual position of the front between two characteristic branches of the general circulation may be very far removed from the mean position as indicated by the line of convergence of the wind systems on the mean wind charts. On the other hand, if we designate the mean position of such a region of frontogenesis as a climatic front, then we can say that such a climatic front will be a region of maximum frequency of migratory cyclones. Such a region which will be characterized in its climate by a maximum frequency of warm, cold, and occluded front passages with their attendant cloud systems and typical rain belts, and a maximum frequency of change of the prevailing air mass type. Bergeron has represented, on the basis of Köppen's mean wind charts for the northern hemisphere in January and July, respectively, the winter and summer positions of the principal climatic fronts on the northern hemisphere, and shows in general how the resultant scheme fits the observed facts. He distinguishes between the arctic, the polar, and the tropical fronts. The arctic fronts are the most northerly, the air masses to the north coming directly from the arctic. On the polar fronts of middle latitudes we find the contrast to be essentially that between the subpolar and the subtropical air masses. On both of these fronts there are large temperature differences. Therefore the arctic and polar fronts are characteristically regions favorable to the genesis and maintenance of extra tropical migratory cyclones, with all the weather sequences which that implies. The tropical fronts, on the other hand, are distinctly different. They represent essentially convergence of subtropical and tropical air masses, whose temperature differences are characteristically small. They are primarily regions of light variable winds between the prevailing wind systems of the subtropics and tropics, such as the doldrums. Hence they are characterized by oppressive heat and over the oceans by high humidity, heavy instability showers, and under favorable conditions even by tropical hurricanes, but not by clearly marked front passages or typical warm and cold front rain belts.

Obviously the climate at any place depends on the prevailing air mass type, and the frequency of front passages, i. e., nearness of the climatic fronts. Both of these in turn depend upon the position, extent, and activity of the different centers of action. Therefore the fundamental problem of a dynamic climatology which aims to present the underlying dynamic and thermodynamic phenomena of the atmosphere in their entirety is to account completely for the mean activity of the centers of action. The first step toward the solution of this problem is the development of some satisfactory method of representing the state of activity of the centers of action, in order that normal and abnormal conditions may be clearly represented and recognized. For this purpose Bergeron used Köppen's mean wind charts as the best means at hand for a preliminary study.

An understanding of the dynamic and thermodynamic factors controlling the centers of action will explain not only the mean activity of these atmospheric phenomena (climate), but also variations in and departures from this mean activity. The shortest and most irregular of these changes we refer to as changes in the weather. For instance, Bergeron shows, in accordance with Köppen's mean wind chart for January, that for this month in the eastern United States the climatological front (polar) between the cold continental air masses of the North

American winter anticyclone and the warm maritime air masses belonging to the circulation of the Bermuda high (westward extension of the Azores high) extends from southern Florida northeastward to the vicinity of Bermuda and on into the north Atlantic. Thus Köppen indicates prevailing northwest winds on the north Atlantic and northeast on the south Atlantic coast. On the other hand, we know that this front, even in winter, may be displaced northward as far as to the Canadian border, and again far southward until lost in the trade winds as the successive warm and cold outbreaks belonging to the two circulations advance and recede. Always the cyclones tend to develop and move along the front as it is displaced. Such changes as these constitute weather, and have no place properly in a discussion of climate. Yet in the aggregate they determine climate, and as we shall see presently, no hard and fast line can be drawn between weather and climate, either in definition or in the controlling factors.

Besides the irregular variations of a few days or weeks which constitute what we call the weather, there have long been observed, statistically, anomalies of the various meteorological elements of months and even years, some of which recur with a certain degree of regularity. Such anomalies will usually be found associated with some abnormality in activity or position of one of the centers of action. Whether variations such as these will be classed as climatic changes or not depends entirely on the arbitrary choice of the period of time which shall be considered sufficient to determine a climate. Yet we know that even if centuries are used in establishing climatic means, still changes of climate take place. There occur meteorological anomalies of every length from a few days to thousands of years, and of every degree of irregularity, yet they are all apparently associated with the same sort of abnormalites in the centers of action, whatever the underlying causes. Hence it becomes evident that in climatology, as well as in the study of the daily weather, it is necessary to consider not only mean or normal conditions, but also the disturbing factors.

A good instance of an anomaly lasting a few months is that of the drought which reached its peak in the eastern United States during the summer and autumn of 1930. During that time the Bermuda high was unusually well developed to the westward, therefore, persistently predominant in the circulation of the southeastern United States, so that the polar front, or cyclone path, was displaced northward from its normal position. As a consequence the normal cyclonic or frontal rain was largely missing in the eastern United States, and this in turn lessened the evaporation from the earth's surface which probably is the source of the greater part of the moisture of summer showers and thunderstorms. There are many well known more or less irregularly periodic displacements of this sort of considerably longer duration. Probably the best known and most studied of these longer period displacements of the climatic fronts are those connected with the 11-year sun spot cycles. As to the reality of many of these changes there is not the slightest doubt, but in the dynamic or thermodynamic explanation of them not even a beginning has been made. Some of the factors, which have been suggested as of importance in the control of climate and climatic changes (see Humphrey's Physics of the Air, Pt. V), may be listed as follows:

(1) *Radiation.*—(*a*) Solar: Variations in the solar constant, such as those belonging to the 11-year sunspot cycle and possibly others of longer or shorter duration.

(*b*) Atmospheric: Changes in the atmospheric composition (especially the amounts of water vapor, ozone, or carbon dioxide) or of its content of impurities which reflect or scatter solar radiation (especially volcanic dust).

(2) *Changes in the earth's surface.*—(*a*) Glaciation: This favors both by radiation and reflection further cooling of the overlying atmosphere and the strengthening of local anticyclonic circulation.

(*b*) Desiccation: Increasing aridness over a portion of the earth renders that region one of greater extremes in climate.

(*c*) Distribution of land and water: Changes in the position or ratio of land and water areas must affect the nature of the general circulation profoundly, for they seem principally to determine the centers of action. Furthermore, orographical changes may greatly affect the atmospheric circulation and climate, while the influence of similar changes in submarine orography on the oceanic currents may have an equally far-reaching effect on climate.

(*d*) Ocean surface temperatures: Anomalies in ocean surface temperatures and currents much like those in the atmosphere are generally recognized phenomena. These may in part be caused by atmospheric irregularities, but certainly there are also independent factors involved. These must be taken into account especially in explaining the short period atmospheric anomalies. It is very difficult to distinguish between cause and effect in atmospheric-oceanic interactions.

(3) *Persistent tendencies in the circulation of the substratosphere.*—It has been shown analytically and statistically that for short period surface pressure variations the warm and cold air currents of the substratosphere (actually warm and cold here, not relative to the surface) play an important rôle. Even important irregular change in the greater centers of action are frequently explained in this way. Clearly then, whatever the dynamic and thermodynamic controls of the circulation at the base of the stratosphere, persistent or variable tendencies in the circulation here will have corresponding secondary effects at the earth's surface.

It is scarcely necessary to point out how fundamental for the problem of long range weather forecasting is the development of a comprehensive dynamic meteorology in the sense outlined in this paper. In fact, the two problems are identical, for such a dynamic climatology is nothing other than the physical basis of long-range forecasting. At present there are numerous schools of thought which have been developed in connection with this problem, each based on only one or two of the abovementioned factors of climatic control, and usually mutually exclusive and even antagonistic. Furthermore they are entirely empirical, based on experience or correlations and utterly lacking in any attempt at dynamic explanations. A dynamic climatology that can finally explain the intensity and displacements of the centers of action and of the climatic fronts will make possible the forecasting over considerable periods not only of the cyclonic activity and frontal rain, but also of the prevailing air mass types with all the attendant weather phenomena.

To sum up, we might say that if a dynamic climatology is to aim at a presentation of the several complete thermodynamic units controlling the climate of a region rather than the unrelated distribution of the individual meteorological elements, it should be developed somewhat as follows:

(1) Some method of representing the position, horizontal extent, and degree of activity of the different centers of action should be chosen, so that mean values and long-period departures from the means may be found and

studied. For this purpose Bergeron has made use of Köppen's mean wind charts as the best available criterion.

(2) Mean positions and long-period departures from the mean positions of the climatic fronts must be noted. Explanation of departures from the normal position of such zones, i. e., displacement of the belts of maximum storminess, or cyclone paths, must be looked for in the dynamic or thermodynamic factors (see list above) controlling the particular center of action whose displacement or changed activity is responsible for the displacement of the climatic front.

(3) Finally there is required the systematic observation of the frequency of occurrence of warm and cold air masses at each station, and the relation of all the meteorological elements, especially the hydrometeors, to the prevailing air mass type. The frequency of change from one air mass to another should give in temperature regions a measure of the proximity and activity of the climatic front, and an indication of the contribution of active front passages to the climate of the region, particularly the precipitation and cloudiness.

WINDSTORM IN THE LOS ANGELES AREA NOVEMBER 22, 1930, AND SOME EFFECTS OF WIND FLOW IN A MOUNTAINOUS REGION

By GEORGE M. FRENCH

[Weather Bureau Office, Los Angeles, Calif., July, 1931]

Near midnight of November 21, 1930, one of the strongest winds of record began in the Los Angeles area and continued until about midnight of November 22. Winds aloft and on the surface were from the northeast except where they were deflected by topography.

Following the passage of a low over the southern portion of the western plateau region on November 18, 1930, a high pressure area moved in rapidly from the Pacific Ocean over the Northwestern States and when reaching the plateau region became almost stationary as is common in that region especially during the early winter months. This high built up rapidly being reinforced by additional ocean highs and as shown on the 8 p. m. synoptic chart of November 21, it was central over Idaho, eastern Oregon, and western Montana with a pressure of 30.82 inches. The pressure gradient had by this time become quite steep between the plateau and the coastal valleys of California and the high was still increasing in energy.

The influence of this high was little felt in southern California as far as either surface winds or those aloft were concerned during the day of November 21, 1930, but a little before midnight on that date surface winds increased rapidly and became strong with frequent gusts of gale force. The next morning, November 22, the synoptic chart showed the high central in Idaho and northwestern Wyoming with the highest reading at Yellowstone, 31.02 inches, reduced to sea level.

Three hourly airway weather maps of California for 11 a. m., 2 p. m., and 5 p. m., eastern standard time, are shown by figures 1, 2, and 3. As the map is on quite a large scale, isobars are drawn for every 0.05 inch difference in pressure. These maps show the steep gradient that prevailed over the mountains on November 22 and the relatively low pressure on the lee side of the mountains, which is largely due to the strength of the wind.

From experience the writer believes that under ordinary pressure gradients, mountains as high and as precipituous as the San Gabriel Range act as a barrier to north winds in the Los Angeles area. In such cases high winds proceed southward over the mountains and remain aloft, gradually lowering and reaching the surface in the vicinity of the ocean shore line or farther out, leaving the Los Angeles area in light to moderate variable winds. However, in such cases the wind pours through the low points in the mountains, as for example Cajon Pass, and frequently proceeds southward at gale force through Santa Ana Canyon in the Santa Ana Mountains and thence southward to the ocean, thus producing the "Santa Ana" as the wind of this type has been popularly called in southern California. I once had the opportunity to observe such a wind from the top of Santiago Peak. The course of this rapidly moving air was easily traceable by the dust and could be followed in that manner from Cajon Pass to the ocean.

It appears, by study of winds in the Los Angeles area, that if the gradient is quite steep between the plateau high and the coastal area that high northerly winds in passing over the mountains will not only reach the surface in lee of low passes but will also follow the contour of the lee side of the high mountains and in that case high northerly winds are general over the whole Los Angeles area as was the case on November 22, 1930.

There were three points in and near Los Angeles where wind instruments were located at the time of the storm. They were located as follows: Weather Bureau office, Los Angeles; airport at Alhambra, and the Weather Bureau airport station, Glendale. The writer was located at the latter point. The strength and duration of the wind was quite similar at Glendale and Alhambra but the velocities were lighter and the duration much shorter at the Weather Bureau office, Los Angeles, a condition that frequently prevails in times of high northerly winds. The Weather Bureau office in Los Angeles is remarkably free from high northerly winds although the exposure is excellent.

The high winds at Glendale had two maximum periods on the surface, 2 to 4 a. m. and 12:30 to 4 p. m., with gusts in excess of 60 miles per hour during the latter period. As far as could be ascertained, the highest winds aloft occurred near the middle of the forenoon.

The first upper air observation on the day of the wind storm was attempted at 3 a. m. but with several attempts only 3 minutes were secured due to dust. Shortly before 9 a. m. upper air observations were again attempted and after several trials one was secured of nine minutes with an indicated altitude of 5,600 feet. In each of the attempts the balloon moved southwestward rapidly in the beginning then was retarded at approximately the same length of time after release and then would again move out much more rapidly than before. The first attempts were lost soon after reaching the second high velocity either due to dust or to the vibration of the theodolite.

In Figure 4 a cross section of the mountains and valley north and south and passing through the airport station at Glendale is represented. Wind flow over the mountains and valleys is represented by arrows flying with the wind giving my idea of both the nature of the flow over the mountains and the relative speed. The relative speed is indicated by the length of the arrows, longer arrows representing greater speed. This is based on available data and the general knowledge that I have gained mostly in the aerological work of wind flow over a mountain range.

During the wind storm occasionally the wind would suddenly shift at the Glendale station to south or southwest and blow nearly as hard from that direction as it had from the northeast, reaching extremes of 50 miles per hour or more. This is believed to be the result of vertical eddies as represented in Figure 5. This reversing of the wind also occurred at Alhambra but was little noticed at the Weather Bureau office in Los Angeles, which point is farther removed from the mountains.

Flying was discouraged as far as possible in all our contacts with pilots both as to conditions aloft and especially on account of bad wind conditions for landing or taking-off.

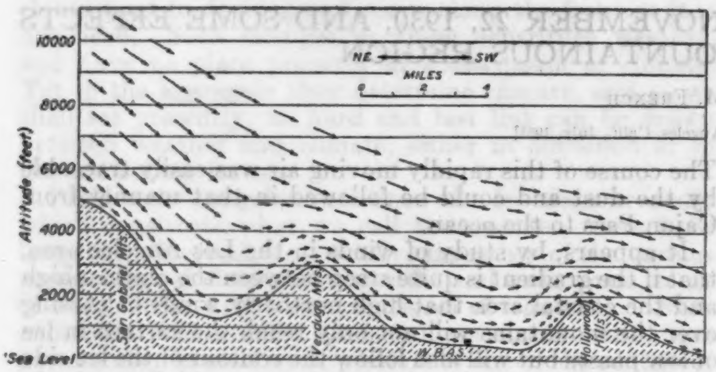

FIGURE 4.—Cross section showing the contour of the land from a point near the top of Sister Elsie Peak, in the San Gabriel Mountains, southwestward through the Verdugo Mountains and Weather Bureau Airport station in the San Fernando Valley, thence through the Hollywood hills near Cahuenga Peak. Arrows indicate the wind flow believed to have prevailed during the greater portion of the wind storm of November 22, 1930

Nearly all the scheduled flights were canceled, but four known flights were made. One scheduled flight was accomplished from Salt Lake City to Los Angeles which was made in 4 hours and 15 minutes as compared with 7 hours and 15 minutes scheduled time. Another flight was attempted from Los Angeles to San Francisco. The pilot came into our office after the attempt and said that he went up to 8,000 feet to avoid extreme bumpiness and was making an air speed of 110 miles per hour.

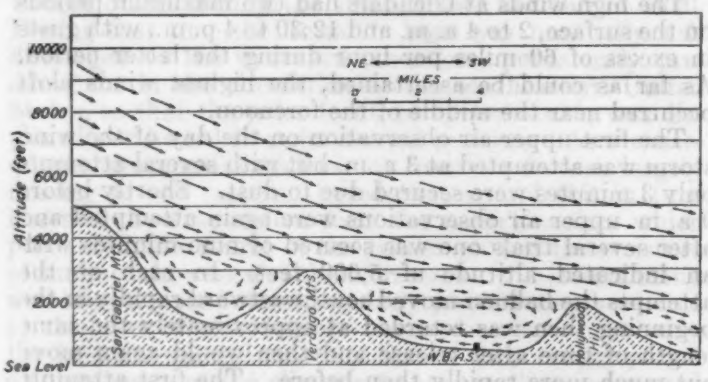

FIGURE 5.—Cross section showing the contour of the land from a point near the top of Sister Elsie Peak, in the San Gabriel Mountains, southwestward through the Verdugo Mountains and Weather Bureau Airport station in the San Fernando Valley, thence through the Hollywood hills near Cahuenga Peak. Arrows indicate wind flow believed to have taken place over this contour on November 22, 1930, showing vertical currents in the lee of the higher hills

He noticed that he was making very little if any headway and he sighted on a water tank below him and found that he was not only making no headway forward but was being carried slowly to one side. He immediately landed at Glendale and found landing conditions very dangerous.

Our upper air observation at 9 a. m. was taken shortly after the attempted flight described above. The following velocities were indicated from the data obtained from the pilot balloon flight (altitudes in feet and wind speeds in miles per hour):

Surface, NNE. 19.	3,200 feet, NNE. 21.
700 feet, NE. 34.	3,800 feet, NNE. 36.
1,400 feet, NE. 51.	4,400 feet, NE. 102.
2,050 feet, NE. 57.	5,000 feet, NE. 168.
2,650 feet, NE. 47.	5,600 feet, NE. 186.

This observation is also plotted on Figure 6 for direction and velocity with elevation in meters and velocity in meters per second.

Again referring to Figure 4 it was found that by comparing distance out of the balloon with the distance of the Hollywood hills from the airport station that the balloon would have reached the area of rising currents and diminished velocity on the windward side at about the time the run showed a sharp decline in velocity. I believe it is therefore safe to assume that the apparent decrease in velocity was partly due to retarded wind movement and partly to rising currents which would indicate a lighter velocity according to our method of determining winds aloft.

The diminished wind velocity on the upper air observation was immediately followed by a rapid increase in velocity which also conforms with Figure 4, as it is believed that the balloon was then entering the increased wind velocity indicated on the lee side of the Hollywood hills and in addition there was a downward movement to the air giving a lower elevation angle than should have been recorded which in turn indicates a velocity greater than what actually existed. Winds undoubtedly occurred, however, of 110 miles per hour or more as evidenced by one aviator's experience.

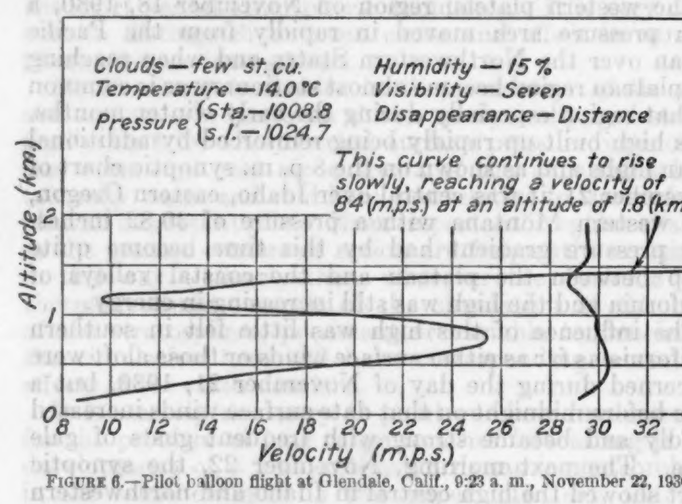

FIGURE 6.—Pilot balloon flight at Glendale, Calif., 9:23 a. m., November 22, 1930

In most cases where strong winds bring continental air into this region, with the exception of cases where precipitation has occurred just previously, very dry and clear weather prevails. However, in this case there was sufficient moisture in the continental air that the forced convection over the mountains formed storm clouds all along the north slope of the San Gabriel and San Bernardino Mountains and blizzards prevailed in that region. The clouds dissipated rapidly on the lee side and the air was relatively dry at Glendale. This storm condition subsided as soon as winds aloft had materially decreased.

Considerable damage was done during the storm. A trimotored plane was torn from its anchorage during the early morning hours at the Grand Central Airport, Glendale, and was rolled by the wind about half a mile across the field and left upside down at the opposite end. The plane was so badly damaged that it could not be

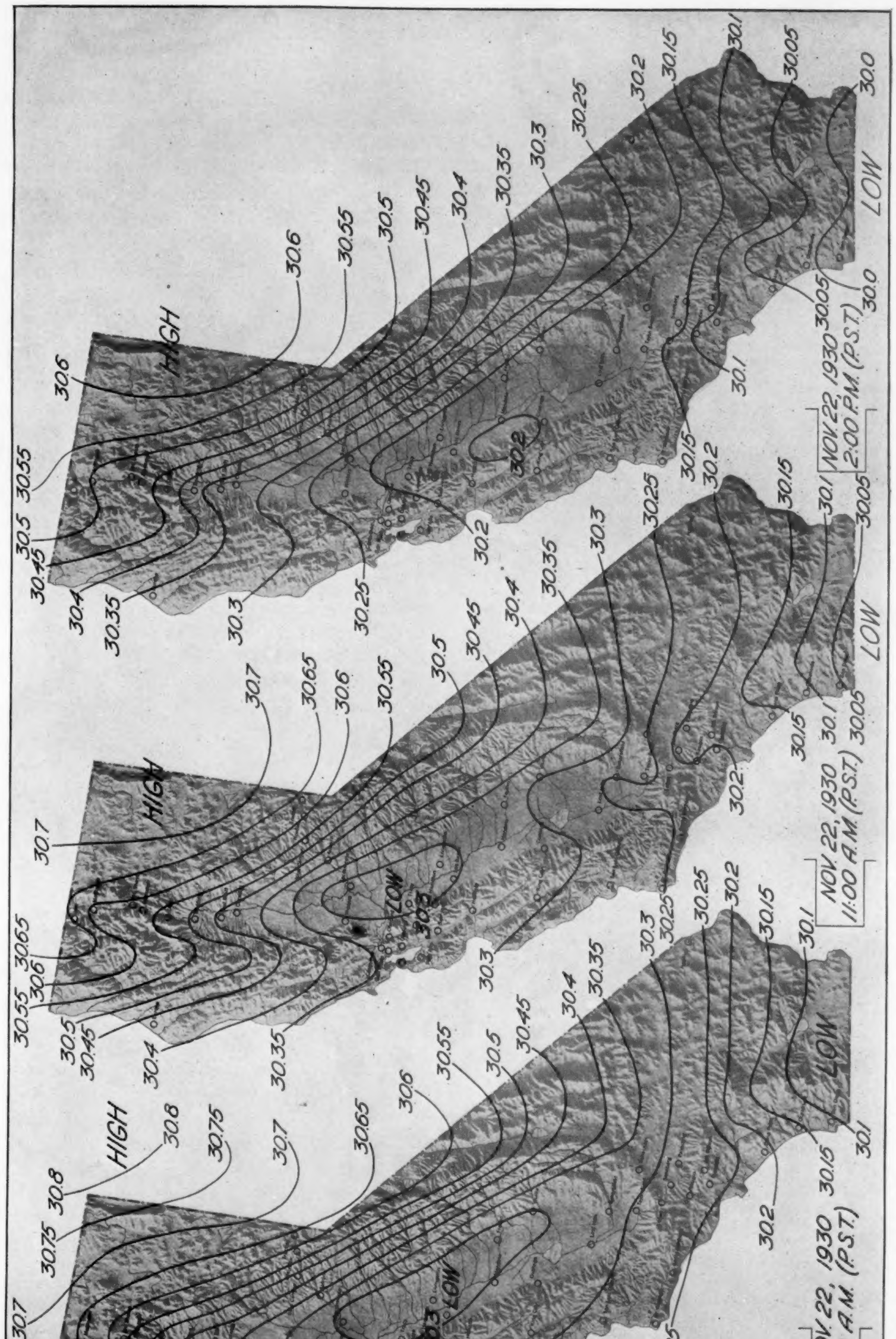

FIGURE 1.—Weather chart 8 a. m. (P. S. T.) November 22, 1930

FIGURE 2.—Weather chart 11 a. m. (P. S. T.) November 22, 1930

FIGURE 3.—Weather chart 2 p. m. (P. S. T.) November 22, 1930

repaired. Other damage, such as small buildings demolished, occurred on the field. In other parts of the city telegraph poles, trees, small buildings, and roofs were either damaged or blown down, and a few people lost their lives by being hit by falling objects.

It is my belief in studying this storm and the available data in connection with other local and general winds in this area that moderately strong winds will generally flow over a mountain having gentle sloping sides, especially if the mountains is not very high, in much the same manner as the flow of air that moves over the cambered surface of an airplane wing, the result being reduced pressure[1] and increased velocity of wind in lee of the highest point. In such cases, I believe that a high precipitous mountain will act as a barrier and the wind will not descend directly down the leeward side but reduced pressure will occur on the lee side as in the other case. When very high winds prevail, I believe that they will often descend the leeward side even of high precipitous mountains, but the flow will be variable and great turbulence prevail.

[1] Detailed airway weather maps for California at times showed peculiar pressure distributions which seemed to be out of harmony with the rest of the map. Mr. D. M. Little first drew these peculiarities to my attention and pointed out that it was due to the compressing of air on the windward slopes of mountains and the expansion on the leeward side as a result of the general wind flow over the region.

THE GOTHENBURG, NEBR., TORNADOES JUNE 24, 1930

By ALFRED RUSSELL OLIVER

Tuesday evening, June 24, 1930, a series of tornadoes began in Lincoln County, Nebr., swept southeastward across Dawson County, and ended in Phelps County, leaving behind them a path of destruction 70 miles long and varying in widths from a quarter of a mile to 2 miles. (Fig. 1.) The storm was first observed about 3 p. m., struck its first blow about 5:30 p. m., and was over by 8 p. m.

The weather map for Tuesday morning, Figure 2, shows that almost the entire United States west of the Mississippi was covered by an area of low pressure. Over most of this area the variations in pressure did not exceed two-tenths of an inch, the extremes being 29.7 and 29.9 inches. Thus the barometric gradient over the

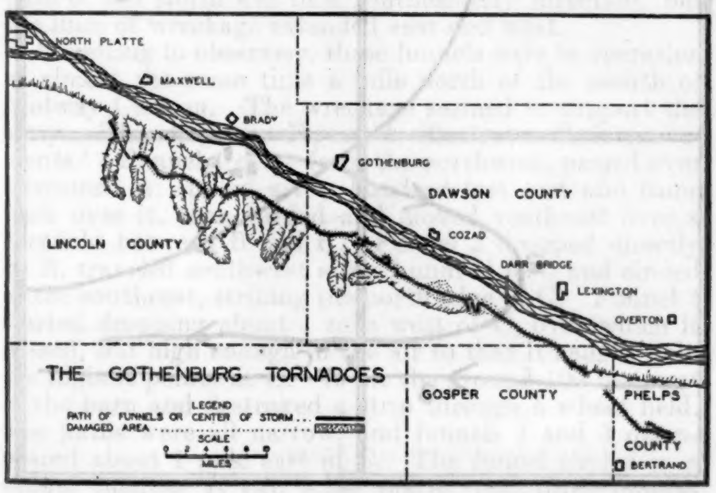

FIGURE 1

entire western part of the country was very slight. These conditions are typical of those which produce the common thunderstorm of this country. A HIGH, with a pressure of 30.1 inches, was centered over western Oregon; another, with a pressure of 30 inches, existed over southern Louisiana. (See figs. 2 and 3.)

The tornadoes occurred between 5 p. m. and 8 p. m. In some cases coincident with them, but generally somewhat later, violent thunderstorms, accompanied by strong winds, occurred at several points in Nebraska, north, south, and east of the tornado belt, but there was no general storm over the State. That tornado conditions seem to have started developing west of North Platte is indicated by reports of violent agitation of the clouds 15 miles west of there. These clouds moved eastward along the Platte Valley. At North Platte two clouds appeared to unite, one coming from the west, the other seeming to materialize out of the air overhead. Both were rolling and tumbling and boiled upward as they came together. The new cloud continued southeastward about 14 miles toward Boxelder Canyon, becoming darker, more agitated, and continuously more threatening. Behind this cloud was the thunderstorm which brought the rain and hail, a not unusual condition under such circumstances.

The location of North Platte in the formative area of the tornado makes the weather observations there especially significant. In this connection it should be

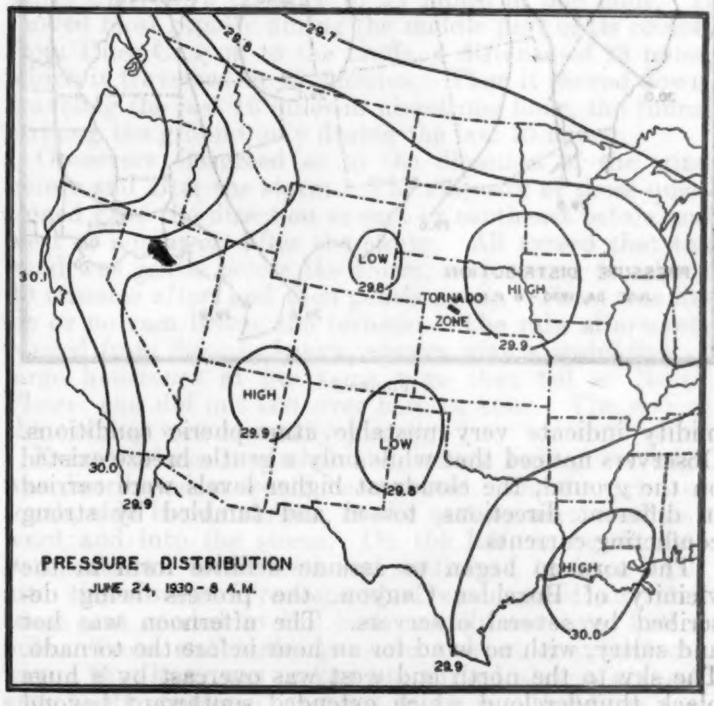

FIGURE 2

remembered that the storm was forming from 3 p. m. to 5:30 p. m. and was over by 8 p. m. A heavy thunderstorm prevailed at North Platte[1] from 3:55 p. m. to 5:45 p. m., with a rain lasting until 4:29 p. m., then a heavy hail for 15 minutes, and then rain again until 4:57 p. m. The rainfall for the afternoon was 0.32 inches. Hailstones 2 inches in diameter were picked up, consisting of from 75 to 100 ice pellets frozen together. A continuous roaring, as of trains passing through a tunnel, was heard before and after the rain and hail. The barometer fell steadily from 26.98 inches at noon to 26.85 inches at 7 p. m. The temperature dropped from

[1] Detailed information concerning conditions at North Platte was supplied by Mr. A. W. Schilling, junior meteorologist there.

86° at noon to 70° at 5 p. m., rose to 77° at 7 p. m., and then began the normal nightly decline. The humidity was slightly above normal at 7 a. m., and about 40 per cent above it at the noon and evening readings. The wind was moderate during the afternoon, but very changeable, as shown by the following table:

1:00 p. m.–4:36 p. m., southeast.
4:36 p. m.–4:37 p. m., south.
4:37 p. m.–4:44 p. m., east.
4:44 p. m.–4:45 p. m., north.
4:45 p. m.–4:49 p. m., northwest.
4:49 p. m.–5:00 p. m., west.
5:00 p. m.–5:04 p. m., south.
5:04 p. m.–________ east.

The variable wind, the rapid drop in temperature, the steadily falling barometer, and the unusually high humidity indicate very unstable atmospheric conditions.

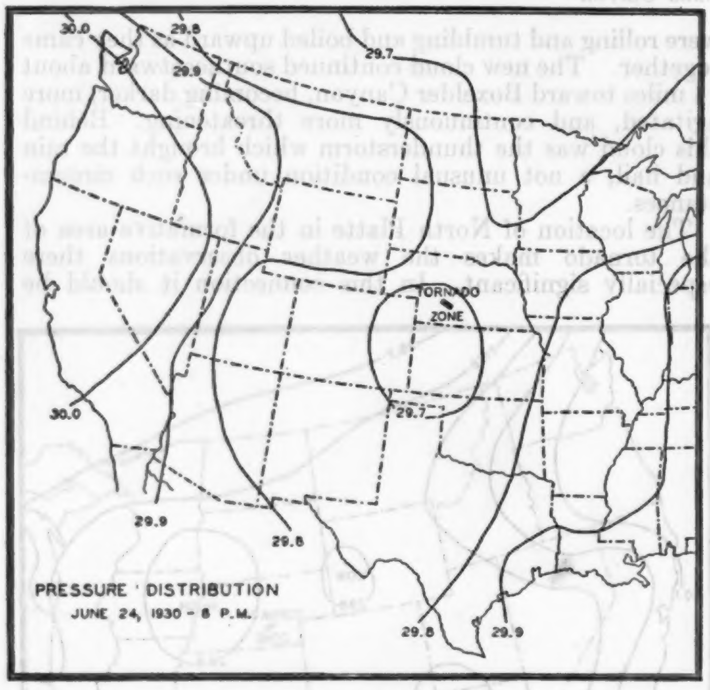

FIGURE 3

Observers noticed that while only a gentle breeze existed on the ground, the clouds at higher levels were carried in different directions, tossed and tumbled by strong conflicting currents.

The tornado began to assume definite form in the vicinity of Boxelder Canyon, the process being described by several observers. The afternoon was hot and sultry, with no wind for an hour before the tornado. The sky to the north and west was overcast by a huge black thundercloud which extended southward beyond the bluffs about 5 miles. Below this were two other layers of clouds. The upper layer, some distance above the ground, was white and traveling due north; the lower layer, close to the ground, appeared to be nearly black and traveling due south; both were moving at high speed. The two did not unite; but the lower layer, which was rolling and tumbling, eventually formed a typical thunderhead on the southeast corner of the main cloud, but lower and slightly in advance of it. This thunderhead, described by some as consisting of several layers, whirled rapidly counterclockwise, rolling and tumbling in all directions within the whirl. One observer said a southwest and a northeast wind seemed to meet head-on about this time and the clouds became still more agitated. Clouds were rushing into this center from all sides. No funnel appeared, but the whole cloud settled close to the earth, and a column of dust about 2 rods wide rose to meet it. The two never united and the dust column soon collapsed. All this time a roar was heard overhead.

The storm traveled southeastward and struck its first blow at Cottonwood Canyon (Fig. 1) shortly after 5 p. m. Its course from Cottonwood to Jeffrey Canyons was a zigzag one. It apparently traveled south, northeast, east, and southeast through this part of its course. Observers some miles north reported that the funnel seemed to whip back and forth in a great arc which they estimated to be 5 miles wide, writhing and twisting like a snake. From Jeffrey Canyon it traveled due east to the valley edge, then turned southeast, following the bluffs to the mouth of Hiles Canyon.

Its path was narrow, never over half a mile wide, while the zone of greatest intensity was only a quarter of a mile wide. At Tree and Gulch Canyons the center was about 500 to 800 feet wide, widening again east of Tree Canyon. About 2 miles east of Gulch Canyon it lifted, passed over four farmsteads, and dropped straight down on Tree Canyon. As it lifted the funnel broke into two parts,

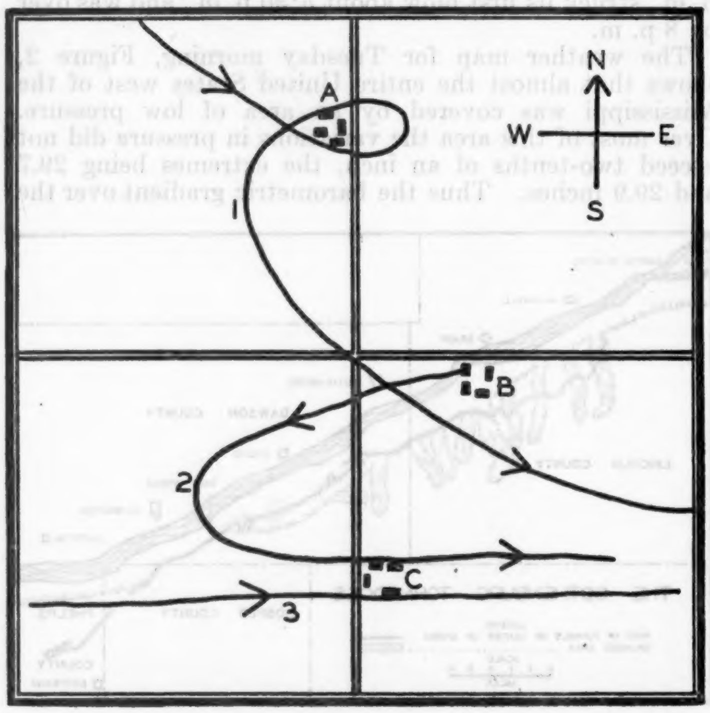

FIGURE 4.—Detail of tornado paths near McDowell farm southwest of Cozad

both whirling independently, the lower finally settling. The upper part gradually lifted and lagged behind until it was pointing due west, parallel to the surface of the cloud above, writhing and twisting. After rising the funnel was white, which seems to have been its usual color when not in contact with the earth. While up in the air no roar was heard and there was no wind on the ground. Mr. Quinn, at Tree Canyon, stood at the cellar door watching the storm approach and thought it was passing over. He estimated the funnel to be 400 feet above the ground. Suddenly the tail began to curl down, and when it struck the ground 300 feet west he jumped into the cellar. The storm lasted only a few seconds there, but he said it sounded like the battlefields of France. At Jeffrey Canyon Mr. Sytsma said it lasted four minutes. It struck Tree Canyon about 6 p. m.

Observers commented on the number of funnels formed, three or four of which were visible at a time.

Over a dozen funnels formed and dropped, but never reached the ground.

From Hiles Canyon the storm traveled east about 2½ miles, leaving the bluffs and moving out into the valley bottom. From this point almost to the end it moved in a southeasterly direction, staying in the valley until it reached a point due south of Lexington. There it passed up over the bluffs to the uplands, where it finished its course. The path varied in width from 1 to 2 miles, narrowing and widening until due south of Darr Bridge. The funnel rose and fell, being high enough much of the time to hit only the taller structures and trees. Due south of Darr Bridge its path narrowed quickly to a width of half a mile, and this was its maximum width for the remainder of its course.

For 2 miles due east of Hiles Canyon it was up in the air, hitting only the higher structures. Then it jumped due south a half mile, missing everything. At this point it dropped to the earth and moved east for 2 miles, wiping out nearly everything in its path. The funnel then jumped 1 mile southwest, doing little damage, but settling at that point to destroy one place.

During this part of its course the cloud continued to drop numerous funnels, some of which reached the ground. Observers testified that a funnel would drop, move due east 1 or 2 miles, and break up; then another funnel a half mile or a mile south or slightly southwest would form and repeat the performance. This story was supported by the lines of wreckage in the field which lay in a due east-west direction, sometimes overlapping a little and always paralleling each other, with little or no damage anywhere on the southward jumps. The path of the storm was in a southeasterly direction, but the lines of wreckage extended east and west.

According to observers, three funnels were in operation at almost the same time a mile north of the mouth of Midway Canyon. The wreckage seemed to support the story. The diagram, Figure 4, illustrates their movements.[1] Funnel 1 came from the northwest, passed over farmstead A, circled a few hundred feet east and came back over it, then turned and moved southeast over a cornfield between B and C. Funnel 2 dropped directly on B, traveled southwest a few hundred feet, and circled to the southeast, striking the north edge of C. Funnel 3 started dropping about 1 mile west of C, over which it passed, but high enough in the air so that it caught only the highest points at C. It hit the ground 100 feet east of the barn and destroyed a strip through a wheat field. The paths were all narrow, and funnels 2 and 3 disappeared about 1 mile east of C. The funnel circled in a similar manner at two other places, and three funnels struck at one other place.

From here the storm continued to the southeast, the path narrowing and the funnel striking the ground only here and there. Due south of Cozad the path widened again, but the point of the funnel remained high enough in the air to hit only the highest objects. South of Darr Bridge the storm became more intense, narrowed to a width of half a mile, and the funnel extended to the ground, destroying nearly everything in its path until it reached the bluffs of the Platte Valley.

As the storm moved across Gosper County it was joined by a cloud from the east and one from the southeast. Another funnel dropped, striking the ground near the Phelps County line, but did no damage west of the line. In Phelps County the storm was as concentrated and violent as in its earliest stages. It moved to the southeast over a path not more than half a mile wide, wiping out several farmsteads. The funnel never left the ground until it finally broke. About 6 miles northeast of Bertrand the funnel, traveling due east, passed over a farmstead. A quarter of a mile east of the farmstead the funnel made a half-circle turn to the left and came back over the same farmstead, moving due west. After passing the farmstead the second time it moved northwest about a mile and a half into a pasture, where it broke up. In both pastures the grass was scoured and beaten, much of it killed, and débris scattered around. It retained its violence to the last, completely wrecking a strongly anchored fence, where it disappeared.

At the end the funnel dipped and rose three or four times, the last time apparently breaking into two parts about halfway up. The lower half continued to whirl a short time and then, according to the account of witnesses, apparently exploded. The upper half lifted into the cloud and the storm was over, about 8 p. m.

The forward movement of the storm was slow. It traveled about 70 miles in approximately 2 hours and 45 minutes, giving it an average speed of about 25 miles per hour. Observers estimated its speed at 20 miles an hour. The rate of movement varied in different parts of its course. It traveled from Boxelder Canyon to Hiles Canyon, a distance of 24 miles, in one hour. It moved most rapidly during the middle part of its course, from Hiles Canyon to the bluffs, a distance of 28 miles, which it traversed in 45 minutes. Then it slowed down, traveling the last 16 miles in about one hour, the funnel striking the ground only during the last 10 miles.

Observers disagreed as to the direction of the wind before and after the storm. The majority of those questioned gave the direction as east or southeast before and west or northwest after the storm. All agreed that the wind was gentle before the storm, very strong for about 20 minutes after, and then gentle again. There was little or no rain before the tornado. The rain afterwards ranged from light to heavy, always with a sprinkling of large hailstones of the same type that fell at North Platte, and did not last over half an hour. The rest of the evening was unusually pleasant.

Except where it circled and struck twice, wreckage was distributed as would be expected. On the right, or south, side it was thrown to the east or northeast, forward and into the storm. On the left, or north, side it was thrown to the west and southwest, backward and into the storm. Wreckage that was carried any distance was carried to the east, usually not over half a mile. Trees and buildings were twisted counterclockwise. One barn was picked up, turned almost around, and, badly shattered, dropped in place. Buildings and posts were plastered with mud on the south and west sides, especially the south. The only exception to this was where the storm circled a place, and here the east face was plastered with mud. The mud was generally half an inch thick.

Examples of explosive action in the center of the storm were frequent. Windows were blown outward, in some instances disappearing without leaving a trace. In several buildings the walls, almost intact, blew outward and the roof dropped on the floor. In some cases roofs were partially or wholly removed, the walls remaining in place but bulged outward. Doors to caves were wrenched open outward. In one case the people reported difficulty in remaining in the cave due to the storm's suction.

[1] It was about 10 to 12 days after the storm before the writer reached the point where the 3 funnels described struck. The entire area covered by the funnels, with the exception of the farmsteads, was cornfield. As it had been cultivated since the storm, it was practically impossible to trace the paths of the storm in the field. The story is based on the account of 6 or 7 observers, some of whom were in the storm area and some a short distance to the side. All told the same story. They also pointed out the paths as given in the diagram, and a little wreckage was found, which seemed to substantiate the story.

At Conroy Canyon there is a cement-lined cistern, sunk level with the ground and covered with a loose board top. It is 16 feet long, 8 feet wide, and 8 feet deep, and before the storm had 4 feet of water in it. According to Mr. Ginapp, the center of the storm passed over it, removed half the top, and sucked out every drop of water. A lake with a surface area of 4 acres is located at the mouth of Tree Canyon, and out of this lake according to the testimony of a Mr. Quinn, who lives nearby, 2 feet of water disappeared.

Examples of scouring were found throughout the course of the tornado. In cornfields lister ridges 8 to 12 inches high were leveled. The best example of scouring was seen at Gulch Canyon. Before the storm all slopes were covered with a heavy growth of grass and low shrubs. Wherever the center struck, grass and shrubs were torn out by the roots, leaving the earth bare. In places even the earth was gouged out. Around this area everything was beaten down as if by a muddy torrent. The transition from this beaten zone to the

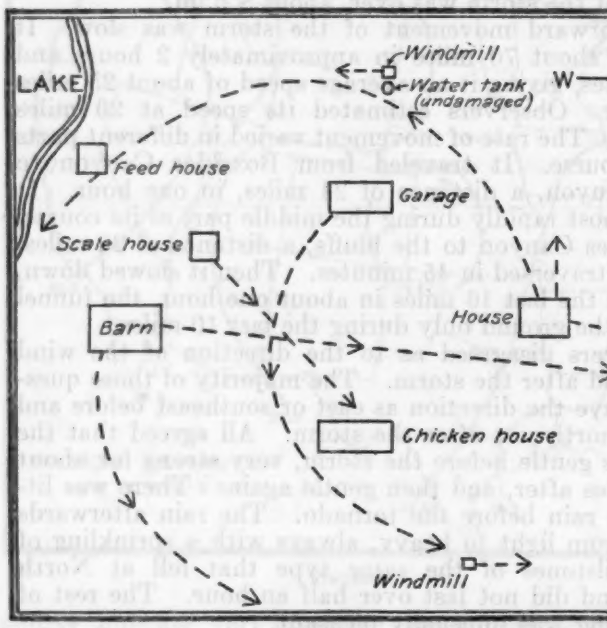

FIGURE 8.—Funnel a few seconds after striking Quinn ranch. The outer, lighter part is believed to consist of débris, dust, and water. Photograph by Mrs. Homer

undamaged zone was abrupt, taking place in a 2-foot strip. There was no leeward, protected slope. It swept up the west slope and down the east without missing an inch, no matter how sharp the crest. Pockets barely big enough to hold a man's body were thoroughly scoured out. Grass, looking as if a muddy torrent had rushed over it, was common throughout the storm area.

The center of the storm passed over an orchard of trees not over 10 feet high and stripped off every leaf and twig, but did not uproot, twist, or break a tree. Similar cases were common. In wheat fields the heads were frequently stripped off and the stem left standing.

Due south of Cozad the funnel passed over the farm of a Mr. Derrickson, destroying the upper part of the barn and the tops of trees and the windmill, but doing no damage to anything less than 30 feet above the ground. Mr. Derrickson was in the barn when the storm struck it. He felt the barn jump, stepped out into the yard, and walked 100 feet to the house, under the funnel which was about 30 feet above him. He said there was no noticeable wind in the yard, not even enough to stir the dust. Overhead it was black as night, and he could only see about 30 feet upward because of the dust and cloud of the funnel.

At one place a big truck was carried 300 feet up a hillside and destroyed. The tires, which carried 80 pounds pressure, were not punctured; but blades of grass were driven between tires and rims. The heaviest iron machinery was so twisted as to be made useless. A cement watering tank, 16 feet across and 2 feet high, was broken in half. One half was moved 20 feet eastward and shattered; the other, intact, was moved 10 feet; but a bag of feathers hanging by an ordinary string from a tree beside the tank was untouched. Brick and cement foundations only 2 feet high and set in the ground 6 inches were shattered. Two concrete blocks, weighing about 2,000 pounds each, were torn from their fastenings and rolled several feet. A combine was rolled and pushed a quarter of a mile and wrecked.

On one farm stood a garage in which the farmer kept his car and a 16-jar Delco light plant. A neighbor drove over to use his cave and parked his car beside the garage. The storm struck and the garage disappeared. The car in the garage suffered no damage except a broken wind shield, while the car outside was destroyed. The home from which the neighbor had fled was untouched. Mr. Sytsma said that 4 glass jars of the battery for the light plant were broken; the other 12 were taken from the shelf, 5 feet up, and placed on the cement floor without cracking any, but 3 were overturned so that the water escaped.

There were several places where almost every move of the center of the storm could be traced, but one of the best was about 4 miles northwest of the mouth of Midway Canyon. At this point stood a farmstead with several fine buildings and large feed yards surrounded by trees, the whole about a quarter of a mile square. The center of the storm passed over it and extended little, if any, beyond the trees. On the east side the trees were left pointing to the east and northeast, on the north to the north and northwest, on the west to the west and southwest, and on the south to the east and northeast. Toward the center they pointed in all directions, but plainly showed a counterclockwise twist. The buildings in the center were completely wrecked and the wreckage scattered to the east.

The Quinn ranch, at the mouth of Tree Canyon, also offered an excellent opportunity to study the movements of the air currents in the center of the storm. The farmyard is about 1,000 feet long from northeast to southwest. The funnel crossed it at right angles and was about 500 feet wide at this point. The north and south ends of the yards were not damaged, while the central portion was destroyed. Figure 5 shows the lines on which the wreckage was distributed by the storm. All wreckage not dropped in the yard was carried eastward for distances not exceeding half a mile. Wreckage from the house was scattered in three directions. The chimney was thrown to the north, the walls, roof, and most of the furniture were carried along a curved line to the northwest, while the floor was carried eastward. Some of the furniture on the floor dropped into the basement. Twenty-two tons of baled hay in the barn were carried eastward, while the rest of the wreckage was scattered along the curved line to the southeast. The wreckage of the feed house was found 1,000 feet to the east. The path of the wreckage from the chicken house was not determined.

Trees varied noticeably in their ability to withstand the storm. Cottonwoods were damaged the most, while pines and cedars suffered the least.

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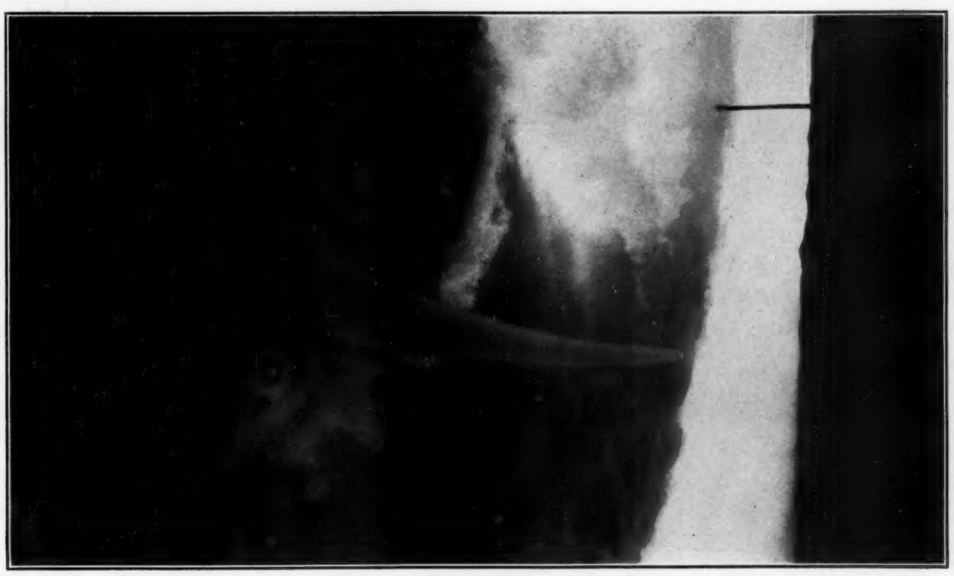

FIGURE 5.—Distribution of wreckage at the Quinn ranch at the mouth of Tree Canyon, about 6 miles southwest of Gothenburg

FIGURE 6.—Funnel approaching Quinn ranch at Tree Canyon. View taken by Mrs. Ray Homer from a point one-half mile east of the funnel

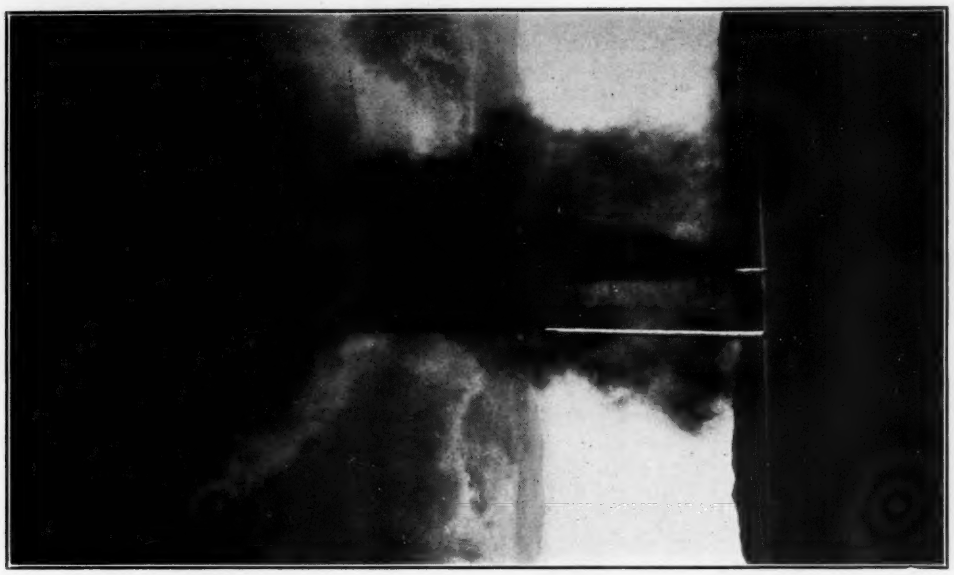

FIGURE 7.—Funnel at the moment of striking the Quinn ranch. Photograph by Mrs. Homer

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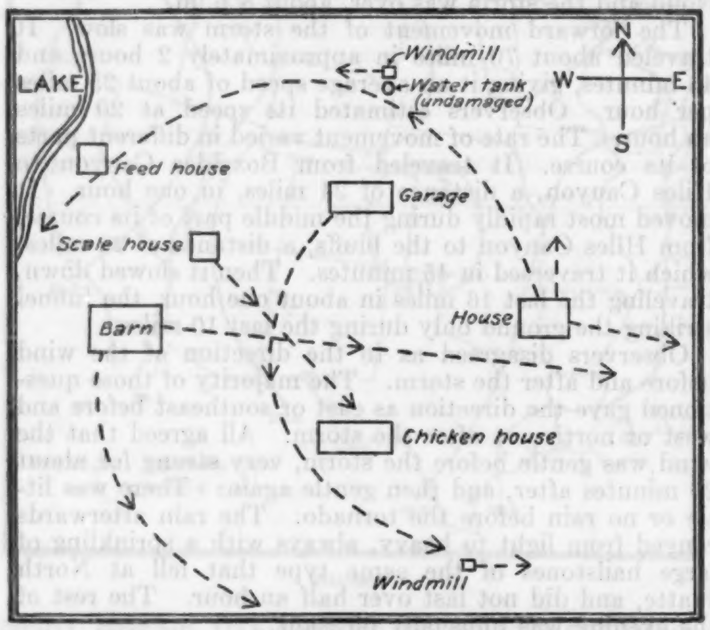

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FIGURE 5.—Distribution of wreckage at the Quinn ranch at the mouth of Tree Canyon, about 6 miles southwest of Gothenburg

FIGURE 6.—Funnel approaching Quinn ranch at Tree Canyon. View taken by Mrs. Ray Homer from a point one-half mile east of the funnel

FIGURE 7.—Funnel at the moment of striking the Quinn ranch. Photograph by Mrs. Homer

$20,000. Only one life was lost and five people injured. The low loss in life and property was due to three causes. The storm struck only rural sections throughout its course. It moved slowly, about 20 miles an hour, making it easy to get out of danger. It was visible for miles, and nearly everyone had watched it for at least 15 minutes before it struck. Word was also sent in advance by telephone.

The storm seems to have been due to conditions in the upper atmosphere, rather than unequal or extreme heating of the earth's surface. A check of the pressures, temperatures, and wind velocities reported from the stations surrounding North Platte revealed only slight differences. There was no hot wave before the storm; in fact, the week preceding had been rather cool. Strong contrary winds were observed tossing the clouds at different levels before there was any sign of a tornado, while it was nearly calm at the ground. One observer said that it seemed to him as if a southwest and a northeast wind had met head-on overhead and started a whirl which began to enlarge and suck the clouds in toward it. The large number of funnels formed would indicate that a number of eddies existed in the upper atmosphere, but not all had strength enough to reach the ground. Some observers said that the tornado cloud seemed to consist of several layers at first. The make-up of the hailstones would indicate the presence of several levels of air with different temperatures.

HAIL DAMAGE IN IOWA

By CHARLES D. REED

[Weather Bureau, Des Moines, Iowa]

Assessors in Iowa are required to ask each farmer on about 210,000 farms as to the amount of hail damage to crops on his farm the preceding crop season. These data are tabulated and summarized by the weather and crop bureau of the Iowa Department of Agriculture.

Eight years of these data are available at the close of 1930. In that period the average annual hail loss in the State was $4,513,760, while the average value of the crops at risk was $391,483,456. The greatest loss, $7,975,686, was in 1925, and most of it occurred in the storm of August 18, extending from the southeast corner of Poweshiek and the southwest corner of Iowa Counties, almost due southeastward about 60 miles across Keokuk, Washington, Jefferson, and Henry Counties and into Lee County. The total damage in this storm was approximately $5,000,000, making it probably the most destructive in the history of the State. The least damage was $1,598,963 in 1930.

The greatest county damage was $1,076,280 in Woodbury County in 1929, and the greatest township damage was $321,380 in Liberty Township, Keokuk County, in 1924. The average number of townships reporting hail damage in the past eight years is 563, or 35 per cent of the total number of townships. In 1929, only 387 townships, or 24.1 per cent, reported hail, which is the least in the eight years, but the damage in these townships was rather intense, so the total was greater than in 1930.

Data are insufficient to work out definite zones of damage, but it now appears that the counties along the Missouri and Big Sioux Rivers and those adjacent are more subject to hail than other portions of the State, while a good many counties in southeast Iowa, particularly Davis, are nearly immune. In the 8 years, 24 counties had one or more years with no damage; 14, mostly in the southeast, had only 1; 4 counties, Dallas, Henry, Louisa, and Monroe, had 2 years; 5 counties, Des Moines, Jefferson, Lee, Van Buren, and Wayne, had 3 years; and 1 county, Davis, had 4 years without hail damage.

In the eight years, 159 townships, or about 10 per cent of the area of the State, reported no hail. It was found that in several cases considerable damage was reported by monthly crop reporters and others in some of these 159 townships from which the assessors reported no damage. This discrepancy may be explained by the fact that crop reporters make their reports immediately after the storms occur, and at certain stages crops, especially corn, in a favorable season, have been known to largely recover from what at first appeared to be almost total destruction. Some months later when the assessor visits the farmer, the crop harvested is so nearly normal in yield that the farmer has forgotten all about the damage.

On the other hand, hail damage is so extremely localized, being large on one farm and amounting to nothing on an adjoining farm, that the actual acreage that escaped damage in the eight years is no doubt greater than the 10 per cent shown by using the township as a unit, and may be twice that amount.

It is recognized that the fluctuating values of crops of nearly equal quantity, or the inflation and deflation of the dollar, makes the dollar an unsatisfactory unit for measuring and comparing hail damage over a long period of years; yet it is convenient; a more complicated method might break down the cooperation of assessors and farmers; and eventually refinement may be effected by applying some commercial index number. The per cent of damage requires no such refinement. It is found by dividing the total damage (times 100) by the total value of crops at risk. In this 8-year period it averaged 1.15 per cent, the greatest being 1.99 per cent in 1925 and the least 0.50 per cent in 1930.

Further details are shown in the accompanying table.

Experience of hail insurance companies shows a larger per cent of damage than these figures indicate, for the reason that it is easy to write policies in a territory where devastating hail storms are of almost annual frequency, and relatively hard to write policies in a county like Davis, where damage is rare. The rates of the companies must therefore be basicly higher and must, in addition, include the cost of getting the business, adjusting the losses, setting up reserves, maintaining offices and employees, and general overhead expenses.

If this line of inquiry is continued long enough, possibly when 20 years of data are available, a more satisfactory scale of county or even township rates for hail insurance may be worked out.

Hail damage in Iowa

[Reported by township assessors]

Year	Damage and risk			Area of damage		Largest county damage		Largest township damage		Counties reporting no damage
	Total damage in State	Total amount at risk	Per cent of damage	Number of townships reporting damage	Per cent of all townships in State	Amount	County	Amount	Township and county	
1923	$2,310,507	$382,987,102	0.61	451	28.0	$233,336	Poweshiek	$70,094	Bear Creek, Poweshiek County.	Dallas, Davis, Des Moines, Dickinson, Guthrie, Jefferson, Lee, Louisa, Van Buren, Washington, Wayne.
1924	6,903,909	422,087,377	1.64	598	37.1	690,259	Keokuk	321,380	Liberty Keokuk County.	Monroe, Wayne.
1925	7,975,686	401,371,307	1.99	748	46.5	592,800	do	180,230	English River, Keokuk County.	Davis.
1926	2,342,187	355,664,129	0.66	465	28.9	415,020	Webster	175,225	Roland, Webster County.	Iowa.
1927	5,064,717	380,753,693	1.33	664	41.2	442,305	Clinton	155,150	Eden, Clinton County	Davis, Dubuque.
1928	6,363,932	439,206,488	1.45	779	48.4	558,966	Plymouth	189,147	Magnolia, Harrison County.	Henry, Jefferson, Louisa, Van Buren.
1929	3,541,179	429,093,048	0.83	387	24.1	1,076,280	Sioux	203,400	Lincoln, Sioux County.	Clay, Davis, Des Moines, Lee, Marion, Palo Alto, Wayne, Winnebago.
1930	1,598,963	*320,704,507	0.50	410	25.5	551,818	Woodbury	83,532	Liston, Woodbury County.	Clarke, Clinton, Dallas, Des Moines, Henry, Jefferson, Jones, Lee, Mahaska, Mills, Monroe, Van Buren.
Average	4,513,760	391,483,456	1.15	563	35.0	570,098		173,395		

*Amount at risk, 1930, preliminary estimate, subject to change.

MELON FROST FORECASTING IN THE UMPQUA VALLEY, OREG.

By EDGAR H. FLETCHER

[Weather Bureau Office, Roseburg, Oreg., April 27, 1931]

INTRODUCTION

Since it occurs to the writer that forecasting frost for the benefit of commercial cantaloupe growing may be a rather new departure in the field of frost protection, a brief outline of the practical application of this service to the melon industry in the Umpqua Valley is presented, with special reference to the part played by fog formation.

CONDITIONS FAVORABLE FOR CANTALOUPE PRODUCTION

The lowlands in the isolated valleys along the South Umpqua River in the general vicinity of Roseburg, Oreg., are being utilized for the growing of cantaloupes of superior quality. The three factors of primary importance—soil, temperature, and moisture—upon which the successful growing of cantaloupes depend are properly correlated here to produce quality and quantity.

The soil of these bottom lands is of silty loam, from 10 to 15 feet deep on gravel through which the river runs, and with a water table so high as to preclude the necessity of irrigation. The vines root down 5 or 6 feet and depend on subsoils moisture, which is supplied by generous winter rains, the summer season being almost rainless. Thus the unirrigated growth, together with the long growing season of cool nights and warm days, not only develops an extremely high sugar content but improves the flavor and keeping qualities, so that melons can be picked fully ripe for shipment almost any distance. The best and finest flavored crops are grown in the years when no rain falls from the time of germination to the end of harvest.

FROST PROTECTION NEEDED

The harvesting season begins about August 15 and continues through the greater part of October. But there is the ever-present danger of frost during the second half of this period; and since it is in the second half that all the growers' profits lie, it stands the grower who wishes to safeguard his season's labor and results therefrom well in hand to consider some method of frost control, especially since the vines will continue to produce until killed by frost.

Experiments, though somewhat crude, in the fall of 1929 clearly demonstrated the fact that frost-control work can be successfully and profitably accomplished on late-maturing melon fields. It occasionally happens that an early fall frost occurs when a large portion of the crop is still unmatured. To protect against a single September frost may be the means of prolonging the growing season for two or three weeks, and just at the time when the market is becoming more favorable. After the coming of the fall rains there is usually sufficient soil moisture to produce fog in the early mornings on radiation nights, thus affording a natural protection against frost damage. But frost hazard is great under any barometric condition with low atmospheric moisture and clear nights.

EFFECT OF WIND

The wind movement, being extremely light in these more or less inclosed valleys, is not usually an important factor to be considered; neither is air drainage, as the valley surfaces are nearly level. However, a change in wind direction during the night to northerly or easterly has the effect of lowering the dew point and consequently preventing the formation of fog which may have been indicated at 5 p. m., especially if clearing does not occur until after that hour.

FOG AN IMPORTANT FACTOR

An essential prerequisite to frost and minimum temperature forcasting in this region is the foretelling of the occurrence of morning fog, together with the degree of density, and the approximate hour of beginning, since occasionally there will be some damage before the fog begins to retard the fall in temperature.

Fog conditions can be determined with great accuracy from the 5 p. m. dew point and relative humidity in connection with the chart shown in Figure 1. This chart shows under what values of 5 p. m. dew point and relative humidity fog has occurred on radiation nights for the fall season at Roseburg during the past 22 years when the minimum temperature was 40° or below. In using the chart, if the hygrometric values fall to the left

of the free-hand-drawn curved line, a clear sky with no fog is indicated, but if to the right of the curve, fog or cloudiness is clearly indicated; furthermore, the character of fog and the approximate hour of beginning can be determined by the departure of the values from the curve. Additional charts may be prepared to show these relationships.

It will be noted that the chart is quite dependable near the middle of the curve, where most of the observations fall. The comparatively few occurrences near the ends of the curve are rather unimportant cases that either occurred late in the season or were followed by minimum temperatures slightly above 40°, and were added to show the hyperbolic trend of the curve. This chart is highly efficient for the purpose intended.

As past records show that fog occurs on a large percentage of radiation nights, there are but comparatively few occasions in a normal year when frost protection is actually needed, as fog often performs this function automatically. But it is on these few nights, if early in the season, that the growers desire to be advised. There is an occasional year when no frost damage occurs during the main producing season.

Figure 2 is a section of the thermograph trace at the temperature station of Dillard, Oreg., on two consecutive nights, showing the rising tendency in temperature after the formation of fog near or soon after midnight. A slight secondary fall occurred with the diminution of fog near sunrise.

The dew point alone will not serve to determine the occurrence of fog as accurately as it will in conjunction with the relative humidity, because in the latter case a factor of the current temperature is also introduced. For instance, an evening dew point as low as 32° may be followed by dense fog before morning if the relative humidity is comparatively high, while, on the other hand, a dew point of 45° may not cause fog if the relative humidity is low. This inverse relationship is well shown in Figure 1.

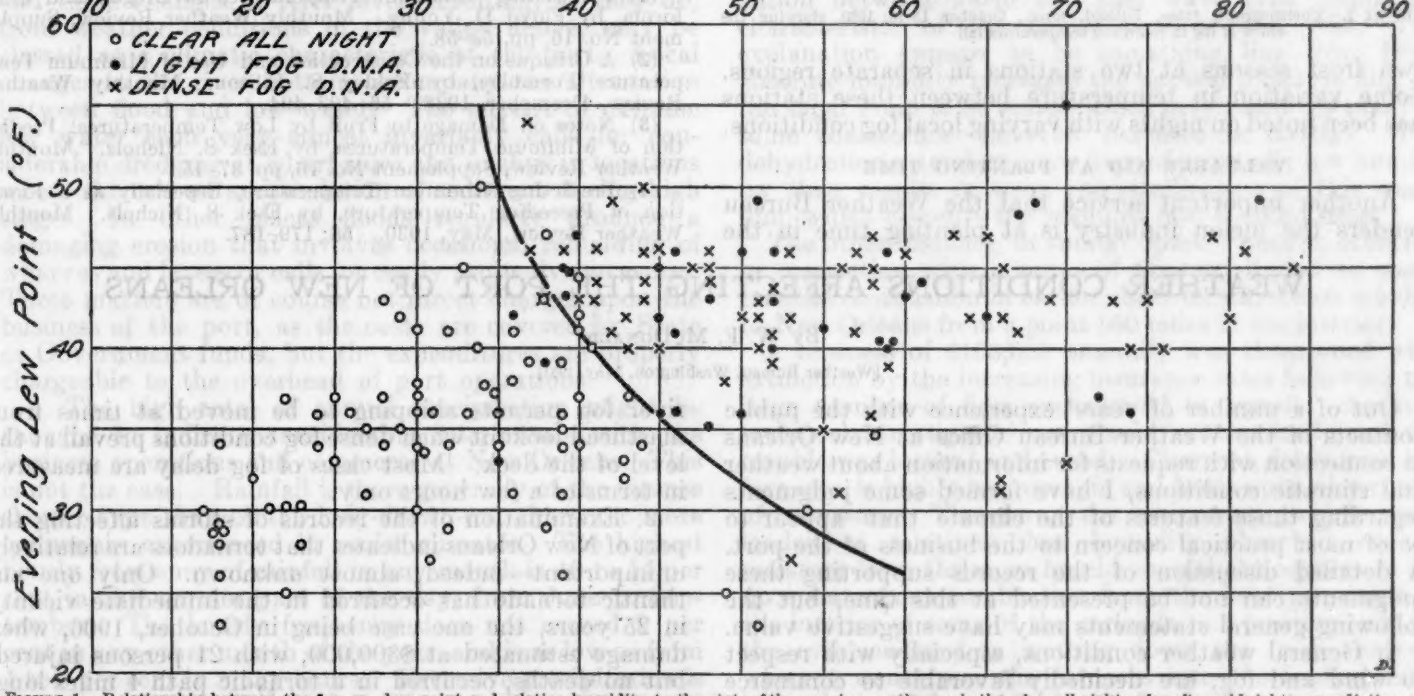

FIGURE 1.—Relationship between the 5 p. m. dew point and relative humidity to the state of the ensuing weather—whether clear all night or fog after midnight—on radiation nights at Roseburg, Oreg., during the fall season of September, October, and part of November for the years 1909-1930, when ensuing minimum temperature was 40° or below. The curve separates hygrometric data when the weather remained clear all night from those when fog occurred

MINIMUM TEMPERATURE FROM FORMULA

When it is evident that the sky will remain clear throughout the night, the ensuing minimum temperature is determined by use of a hygrometric formula developed after the Young method (*1*) (*2*), which has proven quite successful; but the result is checked against a Nichols free-hand curve (*3*) on a hygrometric dot chart based on a long period of record, and in some instances a further slight correction is made.

MINIMUM FROM CURRENT TEMPERATURE

In this locality the 5 p. m. temperature alone, as proposed by Nichols (4), does not seem to be a reliable index to the morning minimum; the moisture factor must be given much weight. Minimum temperatures of 32° or below have occurred frequently on radiation nights with the 5 p. m. temperature varying on different occasions from 45° to 75°. An interesting instance occurred on September 6, 1929; the temperature at 5 p. m. was 80°, the dew point 30°, and the relative humidity 17, but before morning the temperature had fallen to 42° at the Weather Bureau, causing a light frost with some damage to melon foliage in the low valley sections. This range in temperature was caused by cooling from local radiation under favorable conditions of low humidity and practically no wind, calm having been recorded for five consecutive hours after midnight.

VARIATION FROM WEATHER BUREAU KEY STATION

Minimum temperatures on clear nights in the melon districts have been found to be from 6° to 8° lower than at the Weather Bureau key station. However, the variation is somewhat irregular, depending upon local conditions, but as a general rule, when a minimum of 40° or lower is expected at the Weather Bureau, frost will occur along the lower river bottom lands, provided in all cases fogs do not form during the night. As yet no

extensive temperature survey has been made of the district. Thermographs have been exposed only during two frost seasons at two stations in separate regions. Some variation in temperature between these stations has been noted on nights with varying local fog conditions.

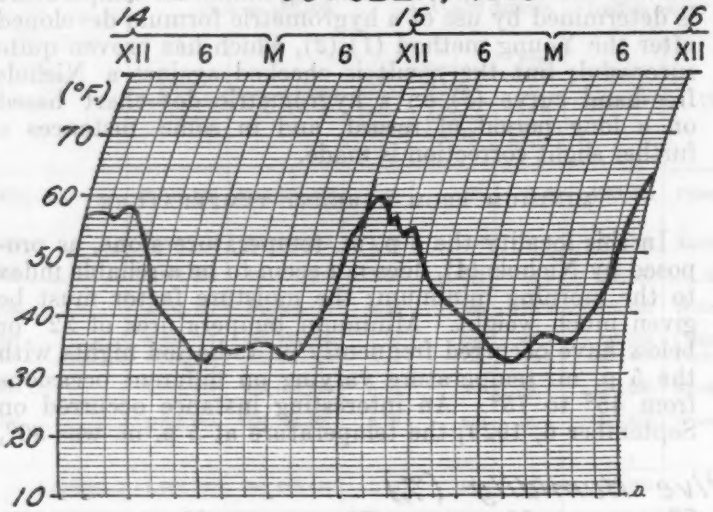

FIGURE 2.—Thermograph trace, Dillard, Oreg., October 15-16, 1930, showing the effect of fog in retarding temperature fall

VALUABLE AID AT PLANTING TIME

Another important service that the Weather Bureau renders the melon industry is at planting time in the early spring, when the weather is still much unsettled. As cantaloupe seed will germinate only under favorable weather conditions, planting must be avoided just previous to a cold, rainy period or one with strong, drying northerly or easterly winds. The kind of weather that is expected to prevail not only determines the time but also the depth the seed should be planted for best results. The growers state that the availability of this service has done much to take one of the major risks of melons in the Umpqua Valley—that of uncertain stands—from the industry. The crop must be started as early as possible after the frost danger is past in the spring in order that the maturing season may be well advanced before the coming of cooler fall weather, with its possibility of frost. Hence, frost protection in the spring is not a factor to be considered.

The aid the Weather Bureau has been able to give the melon growers has played no little part in the development of this rapidly expanding industry in this valley.

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WEATHER CONDITIONS AFFECTING THE PORT OF NEW ORLEANS

By W. F. McDonald

[Weather Bureau, Washington, May, 1931]

Out of a number of years' experience with the public contacts of the Weather Bureau Office at New Orleans in connection with requests for information about weather and climatic conditions, I have formed some judgments regarding those features of the climate that appear to be of most practical concern to the business of the port. A detailed discussion of the records supporting these judgments can not be presented at this time, but the following general statements may have suggestive value.

1. General weather conditions, especially with respect to wind and fog, are decidedly favorable to commerce through the port of New Orleans. Average wind velocities are low, only 7.5 miles per hour for the year, and less than 9 miles per hour in March, the month of highest average wind. Maximum velocities exceed 26 miles per hour on an average of only 15 days per year, and maximum velocities of 45 miles per hour have been exceeded in only 2 of the 12 months, namely, August and September, when tropical storms have caused storm conditions producing higher wind velocities. Fog frequency affecting the water front is not fully represented by the records taken at the Weather Bureau office, but fogs of a duration sufficient to delay commerce more than a day are of relatively infrequent occurrence, and accidents due to fog are uncommon. River fogs are of somewhat greater frequency and duration than those which occur at moderate distance from the river, because the cold water coming down from the north during spring months contributes to highly localized fog formation when warm waves bring moist southerly currents inland from the Gulf to be chilled on contact with the cold river surface. The shallow nature of this localized river fog permits shipping to be moved at times from masthead lookout when dense fog conditions prevail at the level of the deck. Most cases of fog delay are measured in terms of a few hours only.

2. Examination of the records of storms affecting the port of New Orleans indicates that tornadoes are relatively unimportant—indeed, almost unknown. Only one authentic tornado has occurred in the immediate vicinity in 25 years, the one case being in October, 1906, when damage estimated at $300,000, with 21 persons injured, but no deaths, occurred in a tornadic path 4 miles long. Local storms of damaging violence, several of which may have been very small tornadoes or incipient tornadoes, have been recorded on seven other dates in 35 years of records for that vicinity, with damages running over $25,000 in only three of the seven cases.

Ten tropical cyclones are recorded in the Gulf region in 25 years, but only a few of these storms have directly affected the port of New Orleans to more than very minor degree. Shipping bound to or from New Orleans has been lost in a few instances; however, the losses at sea in this period have been remarkably few in the Gulf region, and I dare say less in proportion than the losses to North Atlantic commerce due to extratropical storms.

Only two storms in the weather history of the port of New Orleans during the last 35 years have been weather events of serious magnitude. The greatest damage resulted from the tropical hurricane of September 29, 1915, with an earlier severe but less damaging hurricane of September 20, 1909. Even in these cases, however, the principal maritime losses were confined to the smaller craft, such as tugs, barges, derricks, small river steamers, etc.

There is no doubt that under modern conditions, which permit the Weather Bureau to issue accurate warnings of the existence and progress of hurricanes while they are still at sea, the interests concerned with storm hazards can do much toward safeguarding shipping and commodities from threatened damage. There is also no doubt that a repetition of a hurricane along a track to bring the center inland from the Gulf near and slightly to westward from New Orleans will again cause much damage in spite of all possible precautions. Nevertheless, the storm hazard, measured either in terms of frequency or in percentage of total values lost by storm, is relatively low.

3. The physical location of the port of New Orleans, many miles from open Gulf waters, fully protects the harbor from damage by storm tides. In the 1915 hurricane the level of the river was raised about 6 feet, due to the effects of the tide, but the fluctuation of river levels by reason of the annual flood flow is very much greater than this amount, and ranges upward to 20 feet in a year of large flood.

The fluctuation of 15 to 20 feet in the annual course of river stages does offer some disadvantages to commerce, and these changes in river level, resulting, as they do, from weather conditions in the valley above, may be classed as a climatic characteristic of the port. Local changes in the river bottom accompany the alternation between flood and low water. The advent of extreme low water each year almost invariably calls for considerable dredging at wharf sides and in slips in locations where there is an accumulation of sediment during high stages. In other places floods regularly produce a damaging erosion that involves occasional rebuilding of wharves and levees or calls for costly protective measures. These matters are of course not direct charges upon the business of the port, as the costs are covered by State or Government funds, but the expenditures are properly chargeable to the overhead of port operations.

4. The high total of annual precipitation might be thought to indicate considerable interference with the business operations and commerce at New Orleans. This is not the case. Rainfall is more generally of the intense shower type than of the long-drawn-out character more commonly experienced in cooler climates. The highest hourly frequency of rainfall in any month is 10 to 14 per cent in the warmer part of the day, from June to September. The hourly frequency does not exceed 8 per cent in any other month of the year, and is as low as from 1 to 3 per cent in many hours. Excessive precipitation is less damaging to commerce over the wharves than in other parts of the city, because the river banks are the highest land surfaces, with the slope gradually dropping away from the river, as is common in all true delta regions. Drainage is excellent.

5. While rainfall may thus be shown to be a minor factor in the flow of commerce through the port of New Orleans, it must be admitted that there is considerable difficulty in protecting some commodities from damage by reason of the high *absolute* humidity of the air. Due to the higher average temperatures than those prevailing in other major ports of the United States where *relative* humidities are quite similar, the atmosphere at New Orleans actually carries a much larger quantity of water vapor. Packaged foods, such as cereals, granulated and powdered sugars, canned goods, and some other commodities, as charcoal and chemicals, subject to hygroscopic influences, may suffer considerably in storage and handling due to this feature of the climate.

On the other hand, some commodities are probably handled to advantage because of the higher humidities. Cotton, for instance, received at New Orleans from the more arid regions of the Southwest gains appreciably in bale weights by absorption of moisture, and this change represents gain to the buyer at arid loading point who sells on the weight at New Orleans.

Two other specific examples of the troublesome consequences of high absolute humidity affecting some commodities handled at New Orleans will give point to this phase of the climate in its effects on commerce. Granulated sugar, especially in bags, but to a considerable extent also in wax packages, cakes badly, especially in winter. The remarkable intensification of this problem in winter was difficult to explain on general grounds, because the absolute humidities are of course highest in summer. The cost of handling and regranulating spoiled packages was sufficiently serious to set several of the large sugar companies to a scientific investigation of the underlying conditions. The investigation revealed that the sugar caked most seriously, not when the humidity remained steadily high but when high humidity was followed by a spell of abnormally dry weather. Such variations can only occur at New Orleans with the alternation between warm and cold wave type conditions characteristic of the colder part of the year. The explanation appears to be something like this: High absolute humidity increases the natural moisture film on the sugar grain to an extent which may reach the point of some coalescence between particles in contact. The dehydration attending a few days of unusually low humidity then results in some recrystallization of this sugar film, which cements the granules into a caked mass.

The other instance, of similar obscure nature, occurred in connection with a series of fires attributed to spontaneous combustion in car-lot charcoal shipments moving to New Orleans from a point 500 miles in the interior.

A business of $100,000 annually was threatened with extinction by the increasing insurance rates following the large number of fires experienced in transit. Again a technical investigator was placed on the trail, and the trouble was located and cured. Charcoal, fresh from the furnaces, is highly hygroscopic and heats upon absorption of moisture. Therefore, the shipments which were loaded at relatively low humidity absorbed enough moisture from the more humid coastal atmosphere to set up spontaneous combustion from the heat generated in the interior of some of the carloads. A positive cure for the evil consisted in wetting down the fresh charcoal when it went from the furnaces into the loading bins, where it cured for a few days prior to shipment.

6. Temperature influences on the commerce of New Orleans are in the main unimportant except in connection with one major item of imports, namely, bananas. The critical temperature for bananas is about 40° F., as the fruit does not ripen properly if it has been chilled below that degree of temperature. Unloading of banana cargoes is an open-air process, which is greatly hampered when temperatures fall below 40° and must be stopped entirely when the temperatures fall toward freezing. Average conditions at New Orleans are very favorable for this commerce, as few occasions demand delay or special precaution in transfer of bananas from ship to car.

SUMMARY

Climatic conditions bearing upon the commerce of the port of New Orleans are more favorable than otherwise, with the sole exception of the hazard of severe tropical storm, which is infrequent, having occurred only twice in the last 35 years.

NOTE ON J. F. BRENNAN'S METHOD OF DETERMINING THE ALTITUDE IN THE ATMOSPHERE ABOVE SEA LEVEL WHERE THE FREEZING POINT OF WATER OCCURS[1]

By ANDERS ÅNGSTRÖM

[Meteorological-Hydrographical Office, Stockholm, Sweden, June, 1931]

As regards the very simple method described by J. F. Brennan[1] for determining the position of the zero isotherm in the free atmosphere, the present author may be allowed to add some remarks as a consequence of a number of experiments and tests carried out under his supervision at the Meteorological-Hydrographical Institute at Stockholm. From these experiments I am inclined to doubt the practical applicability of the method of Mr. Brennan, at least in the simple form described in the paper.

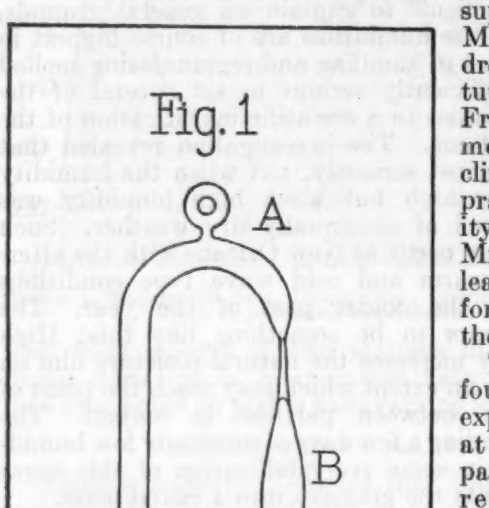

FIGURE 1.—Device for determing the height of the zero isotherm in the free atmosphere

The method is founded upon the expansion of water at freezing. The expansion is used for releasing, at the height at which freezing occurs, a paper pendant from a pilot balloon and the moment of the release is noted. For further details I may refer to the original note of Mr. Brennan.

The great difficulty in the practical application of this method is due to the fact that water does not under ordinary conditions, when no ice crystals are present, freeze at a fixed temperature. Inclosed in a small vessel of glass or metal and cooled down below zero, water freezes at times between −0° C. and −3° C., but may sometimes be cooled down to about −7° to −8° C. without freezing. In shaking the vessel or through blowing small air bubbles through the water we may reduce the probability for a considerable undercooling, but the fact remains that the water even under these conditions may freeze at temperatures varying by a couple of degrees.

Figure 1 shows the design used in our experiments. The water is inclosed in the small glass bulb *b* and in the small capillary tube *c*, connected to the glass bulb. Cooling the system below 0° C. we find that the water will at first freeze in the tube; when the water some moments later freezes in the bulb the capillary is broken and the signal attached at *s* is released from the balloon attached at *A*.

A large number of experiments were carried out in order to prevent the water from undercooling. An automatic shaking device was designed where the vertical movement of the balloon was used for driving a little "shaker." We also investigated whether the addition of powdered substances like fine grains of metals, etc., would help, but with small effect.

Considerable progress however was obtained through stirring the water in order to produce small air bubbles. It seems as if very small air bubbles present in the water would prohibit further undercooling. The smaller the air bubbles, the higher their internal vapor pressure, and the more effective they seem to be in prohibiting a considerable undercooling. The difficulty in the practical application, however, is chiefly the following: When small air bubbles are produced at a certain temperature above zero, the cooling of the water will have the consequence that air will be absorbed and at the temperature at which the water ought to freeze we run the risk that no air bubbles are present. On the other hand too large air bubbles have no or very little effect. Practically, the difficulties are so great as to make this method of preventing undercooling almost useless.

The final arrangement, which, in spite of its effectiveness, is lacking considerably in practical elegancy, consists in letting a part of the water be frozen at the start in order that undercooling may be impossible. For that purpose a second glass bulb *B* (fig. 1) was added, and the freezing of the water in this larger bulb was effected through dipping this part of the glass system, before the release of the pilot balloon, in a Dewar bottle containing a solution of solid carbon dioxide in alcohol. By including a small grain of lead *P* in the bulb *B* ice was caused to form around *P*, in the lower parts of the bulb, in immediate contact with the water in the capillary. The whole glass system was made at a cost of about half a dollar a piece at the Grave Instrument Co., Stockholm.

Experiments with this device made it clear that we may in this way easily freeze the water at a temperature variable within not more than about ±0.5° and generally at about −1° C. Trials, in which two pilot balloons were sent up in tandem and one of them released at the breakage of the glass, gave the same result, comparisons being made with the results of meteorograph ascensions. In spite of some inconveniences inherent to the arrangement of partly "prefreezing" the water, the method undoubtedly includes some advantages, and may probably be considerably improved.

During these experiments the author had the able assistance of O. Nauclèr, civil engineer, to whom sincere thanks are due.

[1] MONTHLY WEATHER REVIEW, February, 1931, vol. 59, p. 75.

ANALYSIS OF THE PRECIPITATION OF RAINS AND SNOWS AT MOUNT VERNON, IOWA

By LYLE L. COTTRAL

[Cornell College, Mount Vernon, Iowa]

Under the direction of Dr. Nicholas Knight, Cornell College, Mount Vernon, Iowa, has for the last 20 years carried on an analysis of the rain and snow precipitated here. The results of much of this work have been published in periodicals of a scientific nature.

The precipitations are collected in clean granite pans, away from trees and buildings, and stored in glass stoppered bottles. The town has no factories and, exclusive of the college, has a population of about 1,700. The sulphuric acid found comes therefore mainly from the coal used in private heating plants. It has been found necessary to deduct 3.55 parts per million from the reading to allow for the formation of the color in the test for the chlorides. The precipitations come from the east or the south, which signify that the salt is carried by the winds from the Atlantic Ocean or the Gulf of Mexico. Due to some criticism special care has been taken in the analysis of the chlorides, which, after considerable work, we have reason to believe correct. The phenoldisulphonic acid method was used with the nitrates. All of the samples were colorless.

The methods used in the analysis are taken from the Standard Methods of Water Analysis, sixth edition, published by the American Health Association.

TABLE 1

No. of sample	Date of precipitation, 1930	Amount	Rain or snow	Nitrates	Nitrites	Free ammonia	Albuminoid ammonia	Sulfates	Chlorides
1	May 5	0.6	Rain	0.04	0.0001	0.056	Traces.	------	14.2
2	May 6	0.25	do	0.06	Traces.	0.04	Traces.	------	7.1
3	June 5	1.5	do	0.06	Traces.	Traces.	Traces.	------	15.62
4	June 13	0.25	do	0.32	Traces.	Traces.	------	------	21.30
5	June 14	0.35	do	0.64	Traces.	Traces.	0.0032	------	------
6	June 15	3.	do	0.64	Traces.	Traces.	Traces.	------	14.2
7	June 25	0.2	do	0.32	0.0002	Traces.	------	------	24.85
8	June 30	0.45	do	0.64	0.0004	0.054	Traces.	------	28.40
9	Sept. 25	0.25	do	0.64	Traces.	0.08	Traces.	------	------
10	Sept. 26	2.0	do	0.64	Traces.	0.08	------	------	38.50
11	Oct. 6	0.25	do	0.32	0.004	------	------	------	31.95
12	Oct. 7	1.90	do	0.64	0.0001	Traces.	------	------	31.95
13	Oct. 16	0.75	do	1.28	0.001	0.064	0.931	0.012	31.95
14	Oct. 29	0.20	do	0.64	Traces.	0.072.	------	------	17.75
15	Oct. 30	0.20	do	0.56	0.0002	0.0752	0.0416	------	------
16	Nov. 15	0.25	do	0.64	0.0017	0.08	0.120	0.044	24.95
17	Nov. 16	1.00	do	0.64	0.0001	Traces.	Traces.	------	24.95
18	Nov. 20	0.4	do	1.28	0.001	0.200	Traces.	------	------
19	Nov. 25	4.	Snow	0.32	Traces.	0.078	0.0496	------	37.15
20	Nov. 30	0.6	Rain	0.64	0.0008	0.0288	0.0160	------	------
21	Dec. 5	0.7	do	0.32	0.001	0.0272	Traces.	------	14.2
22	Dec. 13	5.00	Snow	0.64	Traces.	0.016	0.0144	0.024	17.75
23	Dec. 18	4.	do	0.64	0.0006	0.0192	0.0048	0.146	------
24	Jan. 18	4.	do	0.64	0.0002	0.064	0.0032	0.428	3.55
25	Feb. 6	3.	do	0.64	0.001	0.144	0.192	0.218	10.65
26	Mar. 7	4.	do	1.28	0.0004	0.72	0.04	0.184	3.55
27	Mar. 24	0.3	Rain	0.56	0.0004	0.448	0.98	0.104	3.55
28	Mar. 27	4.	Snow	0.64	0.0004	0.04	0.64	0.068	3.55
29	Mar. 28	15.0	do	0.48	Traces.	0.04	0.04	1.68	7.10
30	Apr. 3	0.15	Rain	------	0.0544	0.800	0.490	3.4	7.10
31	Apr. 9	0.10	do	0.64	0.0128	------	------	0.30	10.65
32	Apr. 16	0.4	do	1.28	Traces.	1.60	0.640	1.4	3.55
33	Apr. 19	0.8	do	0.74	0.0001	0.52	0.245	2.00	3.55
34	Apr. 20	0.5	do	0.64	Traces.	1.200	0.160	1.30	3.55
35	Apr. 21	0.5	do	0.64	0.0001	0.32	0.136	3.60	3.55
36	May 5	0.1	do	0.64	0.001	0.89	0.490	2.00	7.10
37	May 9	0.5	do	1.28	0.0002	0.544	Traces.	2.00	3.55
38	May 11	0.4	do	0.65	0.0004	0.36	Traces.	3.70	3.55
39	May 19	0.4	do	1.28	0.0007	0.64	0.260	------	7.10
40	May 29	------	do	0.32	Traces.	0.04	Traces.	------	7.10
41	June 5	0.25	do	0.64	0.016	------	------	------	10.65
42	June 6	0.75	do	0.64	0.0001	0.08	Traces.	------	3.55
43	June 7	0.08	do	0.64	0.0002	0.98	Traces.	------	3.55

12 inches of snow=1 inch of rain.

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The results of the school year 1930–31 are expressed in Tables 1 and 2. The numbers indicate the parts of the various substances in a million parts of water.

TABLE 2.—*Data from Table 1 converted to pounds per acre*

[1 inch of rain over 1 acre=226,875 pounds]

No. of sample	Nitrates	Nitrites	Free ammonia	Albuminoid ammonium	Sulphates	Chlorides
1	05.445	00.680	07.62	Traces.	------	01.9312
2	03.803	Traces.	02.268	Traces.	------	00.40257
3	20.418	Traces.	Traces.	Traces.	------	05.304
4	18.150	Traces.	Traces.	------	------	01.20771
5	50.819	Traces.	Traces.	00.244	------	------
6	43.522	Traces.	Traces.	Traces.	------	09.656
7	01.452	00.9075	Traces.	------	------	01.12344
8	06.534	04.080	05.508	Traces.	------	02.896
9	03.630	Traces.	04.536	Traces.	------	------
10	29.040	Traces.	36.300	------	------	17.48
11	18.150	22.680	------	------	------	01.8144
12	27.588	00.431	Traces.	------	------	13.792
13	21.780	01.70	10.88	15.827	0.0204	05.44
14	02.904	Traces.	03.262	------	------	00.810
15	------	00.8715	03.407	01.9068	------	------
16	03.176	09.639	04.536	06.804	0.025	01.4175
17	14.520	02.268	Traces.	Traces.	------	05.6725
18	05.808	09.075	18.15	Traces.	------	------
19	09.5832	Traces.	05.850	03.745	------	------
20	04.356	10.88	03.944	02.176	------	------
21	10.164	15.90	04.293	Traces.	------	02.26
22	02.9765	Traces.	01.488	01.395	0.02232	01.674
23	04.352	04.764	01.4231	00.3045	0.109354	------
24	04.352	01.588	04.7936	00.2247	0.3206	00.265
25	03.630	00.5675	08.1868	10.89	0.124	00.6010
26	08.712	03.176	53.928	02.906	0.1378	00.265
27	03.811	03.176	30.464	06.664	0.07072	00.0414
28	04.352	03.176	02.996	04.794	0.0509	00.532
29	14.6125	------	11.344	11.344	------	02.014
30	------	165.376	18.1250	16.66	------	00.242
31	01.452	29.040	------	------	0.06807	00.242
32	11.616	------	54.45	05.808	------	00.322
33	11.616	01.815	94.380	04.45	------	00.633
34	07.260	------	126.080	18.144	------	00.403
35	07.260	01.134	36.288	15.4224	------	00.403
36	01.452	02.27	20.421	11.118	------	00.1611
37	14.520	02.268	62.370	Traces.	------	00.403
38	05.898	03.630	32.670	Traces.	------	00.322
39	11.616	06.3525	58.080	02.359	------	00.645
40	------	------	------	Traces.	------	------
41	03.630	90.72	------	------	------	00.607
42	10.8896	1.70	13.60	Traces.	------	00.604
43	01.161	0.363	17.756	Traces.	------	00.065

INTERPOLATION OF RAINFALL BY THE METHOD OF CORRELATION [1]

By C. E. GRUNSKY

It was in 1885 that it fell to me, as assistant State engineer, to prepare a rainfall map of this State. Records were available at 200 or more stations. It was found that at a large number of these stations observations had commenced in 1871 and that for this group of stations the records, covering 14 years and kept under the supervision of railroad employees, were fairly good. There were only a few widely scattered places in the State at which rainfall records extended back over more than 30 years. It was, therefore, determined to ascertain from each available record the average annual rainfall for this 14-year period and to let the isohyetal lines on the map represent the average rainfall at any point for this period.

[1] The article by Eric R. Miller under the above title, published in this REVIEW, 59: 35, has elicited the account herewith of a method of interpolation followed many years ago in California by Mr. C. E. Grunsky, of C. E. Grunsky Co., engineers, 57 Post Street, San Francisco, Calif. Mr. Grunsky's letter is given above.—*Ed.*

When at any station there was no record for some individual month, recourse was had to the records at near-by stations to approximate the lacking figures. For each such near-by control station the relation of the particular month's rainfall to that of the station's average annual rainfall was then ascertained. The 14-year period only was taken into account in estimating this relation. According to proximity or to similarity of topographic and orographic features, the several approximations thus obtained always expressed in per cent of normal annual rain (in this case the 14-year average), were weighted and were then used to establish the missing record expressed in percentage of the annual normal. This percentage applied to the station normal thereupon determined the desired amount in inches.

At some stations the record covered only a part of the 14-year period. In each such case the incomplete record was compared with the records for corresponding periods at such near-by stations as had complete records. The relation established by this comparison was accepted as the relation between the normal rain at the particular station in question and the normal rain at the control station. If several control stations were brought into consideration the several individual results were weighted, as explained, not by methods of least squares, but according to personal judgment, and the result was accepted with confidence.

It is to be noted, however, that the relation between the amounts of rain at near-by stations is much more likely to be fairly constant in California where the rain producing cyclones are generally of vast extent than would be expected where much rain falls during storms which cover only small areas.

Any refinement of calculation to give better results than can be obtained by the foregoing simple method is never warranted. This will appear when it is considered that the best that can be done is to secure an approximation. The records of the past are, moreover, generally required to serve only as a basis for a prediction of what may be expected to happen in the future. There is, furthermore, always so much uncertainty in the premises that no intricacy of calculation can give any more dependable results than the simple comparison above described.

TESTS OF RAINFALL-INTERPOLATION METHODS

ERIC R. MILLER

[Weather Bureau, Madison, Wis.]

The results of applying to some difficult cases the method of interpolation of rainfall data recommended in the MONTHLY WEATHER REVIEW, January, 1931, may be of interest to meteorologists on account of the light thrown on some unusual rainfall phenomena.

Figure 1 is a scatter diagram showing the correlation of the monthly rainfall in June for 33 years between 1895 and 1930 at Center Hall and State College, Pa., about 10 miles apart. The correlation coefficient for all cases is 0.52; excluding the cases of 1909, 1922, 1930, it is 0.84. Examination of the records shows that local downpours occurred at one or other of the stations in the excluded cases.

A similar diagram for June rainfall, 34 years between 1888 and 1930, for Titusville and Merritts Island, Fla., 17 miles apart, Figure 2, shows that the incoherence that affected only 3 of the 33 cases in Pennsylvania has here spread to the whole group. In spite of this, the wider range of values gives a higher coefficient, 0.61.

A third type of correlation, close for small values, dispersed for large, is shown in Figure 3, January rainfall, 20 years, 1897–1916, Campbell and Boulder Creek, Calif. About 15 miles apart, chosen on account of the large difference in their average January rainfalls, 4.07 and 14.65 inches, respectively.

Mr. C. E. Grunsky, the well-known engineer, has suggested comparison of the regression method of estimating

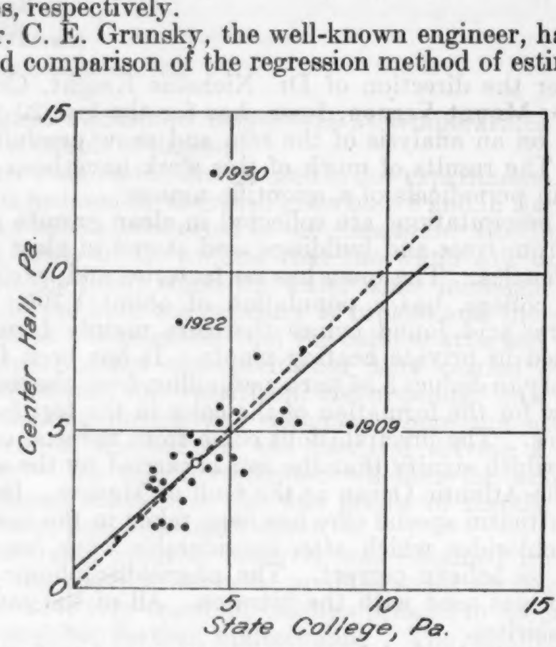


FIGURE 1.—Scatter diagram showing correlation of monthly total rainfall for June for 33 years

rainfalls with a method that he devised in 1885 when, as assistant State engineer of California, it devolved upon him to prepare a rainfall map of the State. The basis of his method is the assumption that the ratio of rainfalls

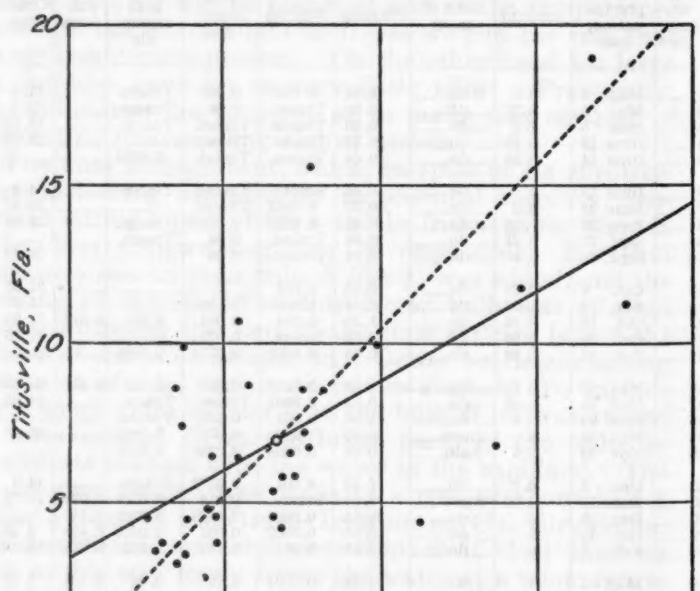


FIGURE 2.—Scatter diagram showing correlation of monthly total precipitation for June, 34 years

at neighboring stations is always the same as the ratio of the normals.

The regression equations minimize the sums of the squares of the deviations of the observed rainfalls from the computed. A suitable test of Mr. Grunsky's method consists in comparing the deviations of computed from observed rainfalls by the two methods.

The regression equations shown in the figures as continuous lines are:

$y=0.84\times 0.54$ Center Hall on State College (1909, 1922, 1930 excluded).
$y=0.57\times 3.03$ Titusville on Merritts Island.
$y=3.11\times 1.99$ Boulder Creek on Campbell.

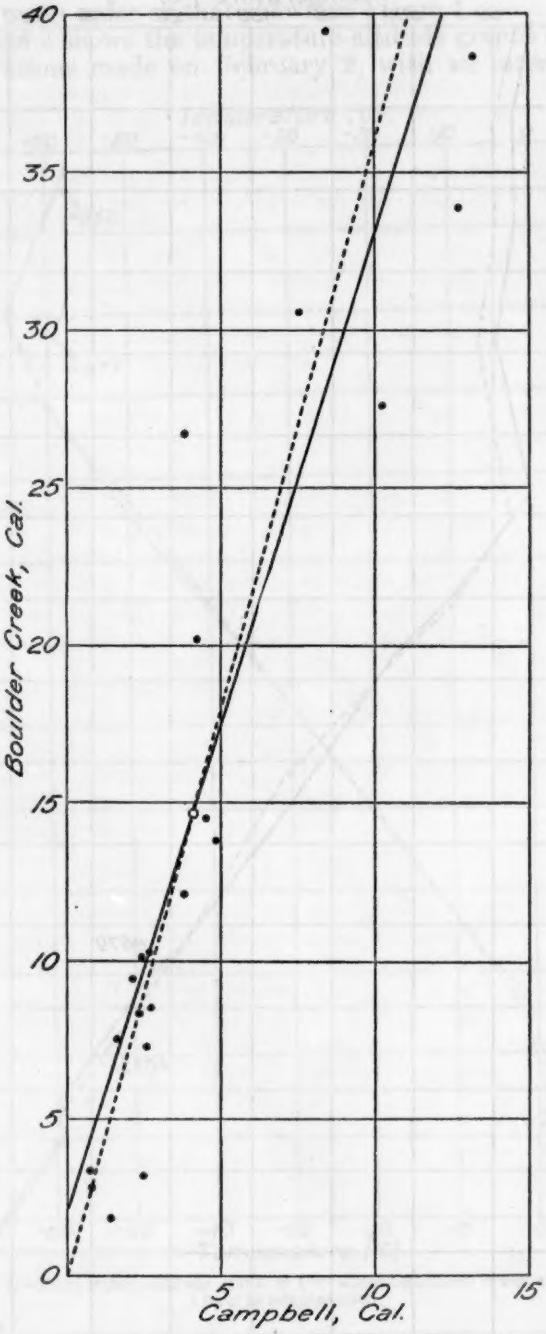


FIGURE 3.—Correlation of January rainfall, 20 years

where the amounts are in inches of rain per month.

The equations representing Mr. Grunsky's method are:

$$y=0.995\times$$
$$y=1.015\times$$
$$y=3.60\times$$

and these appear on the diagrams as dotted lines.

The results of the comparison are as follows:

	Sum of squares of deviations	Standard deviation	Probable error	Mean deviation	Maximum deviation
Center Hall:					
Regression	22.3470	0.86	0.59	0.75	1.85
Normals	29.0337	.97	.67	.77	1.88
Difference	6.6867	.11	.08	.02	.03
Titusville:					
Regression	316.3134	3.05	2.08	2.17	8.14
Normals	329.1524	3.11	2.13	2.39	7.79
Difference	12.8390	.06	.05	.22	−.35
Boulder Creek:					
Regression	527.7698	5.14	3.55	3.80	12.53
Normals	577.5369	5.37	3.72	3.91	12.60
Difference	49.7671	.23	.17	.11	.07

These results indicate that Mr. Grunsky's method is satisfactory for practical purposes, with the advantage of eliminating a great deal of arithmetical work. The normals should be based on simultaneous data.

The preparation of a scatter diagram is not very laborious, and affords valuable information about the closeness of correlation.

HIGH FLIGHTS OF SOUNDING BALLOONS [1]

By E. FRANKENBERGER

[Deutsche Seewarte Hamburg]

The author expresses the fact that most of our knowledge of the composition of the stratosphere is gained by indirect methods, and that it would be valuable if air-soundings, with direct measurements, were made to heights of over 30 km.

In the spring of 1929 the meteorological experimental bureau of the Deutsche Seewarte undertook to solve the problem of getting measurements at high altitudes by systematic sounding balloon flights. Mathematical calculations of the forces of expansion in partially elastic balloons were made, and by research the elastic qualities of balloon rubber and the most favorable amount of gas for sounding balloons were determined. As a result, a sounding balloon on November 2, 1929, reached a height of 35 km.

The question of the dependence of thermometer lag on the rate of ascent is taken up and also the problem of ventilation. The author says that the condition for attaining the greatest altitude is that the balloon rise until is reaches its floating level and then burst. To accomplish this it is stated, they must be inflated so that they rise slowly in the lower levels and that this slow vertical motion (180 to 240 m. per minute) gives poor ventilation. Thus the true temperatures must be calculated from the indicated temperatures by the use of thermometer lag factors. Investigations into the dependence of thermometer lag on air densities and ventilation are in progress for the tropospheric air densities and are under consideration for the small air densities of the stratosphere.

Five balloons 2,500 mm. (98 inches) in diameter were specially prepared for high flights during the international

[1] Analen der Hydrographie und Maritimen Mwteorologie, Jan., 1931, pp. 20-22.

month of September, 1930. The days with high flights were the 8th, 13th, 14th, 24th, and 25th.

Computation of the record of September 8 gave a maximum altitude of 35.9 km. A small Bosch instrument was used and due to the multiple adjustments of the pressure element, a deflection of a few tenths of a millimeter of the pressure pen would produce an error ±3 km. in the maximum altitude. Calculating the height only from the hydrogen filling, the size of the balloon, and from the bursting point and elasticity of the balloon rubber, a maximum altitude of 33 km. is obtained. Also, in favor of the maximum altitude of 33 km. is the fact that with it the rate of ascent in the upper levels is constant, while a maximum altitude of 35.9 km. gives an improbable increase in rate of ascent in the highest level.

On September 13 the balloon was equipped with a large Bosch instrument. For this instrument the maximum altitude of 26.5 km. is probably not more than ±0.5 km. in error. This balloon burst prematurely, due possibly to strain caused by the greater weight of the instrument.

September 14 another small instrument was sent up. It entered a cold current at 24 km. and the balloon stopped rising for a time, then went up again and burst at 32.5 km. The pressures and temperatures of the higher layers were obtained from the descent record.

The ascents on the last two days did not reach the desired heights.

The nine flights in September, 1930, reached a mean maximum altitude of 23 km. It is possible to reach altitudes of over 30 km. only with great care and considerable expense.

The results of these high flights together with the higher Hamburg flights from 1926 to 1930 are to be published soon. These results show that an increase of temperature at heights over 30 km. can not be firmly established. The three highest flights of September, 1930, show minimum temperatures of about −55° C. at about 12.5 km. and temperatures approximately 8° higher at the maximum altitudes. This might be partly due to insufficient ventilation and radiation effect.

The results of the September flights indicate that for further work, investigation should be made into air density and ventilation effects on temperature measurements and the following problems are to be solved: (1) Improvement of the pressure measurements; (2) improving the quality of rubber; (3) development of a connecting apparatus whereby the weight of the instrument is distributed evenly over the balloon.—*Translated and abstracted by J. C. Ballard, U. S. Weather Bureau.*

AGREEMENT FOUND IN RECORDS OF FERGUSSON SOUNDING-BALLOON METEOROGRAPHS

By L. T. SAMUELS

[Weather Bureau, Washington]

During the series of sounding-balloon observations made at Royal Center, Ind., during February, 1931 (international month), two meteorographs were attached to the same balloon in a few instances in order to determine the agreement between the individual records. Also, on a few days sounding balloons were released shortly before and shortly after sunset in order to determine any possible effects of insolation on the meteorograph.

In Figure 1 are shown the temperature-altitude graphs of an observation made February 7 when two meteorographs were attached to the same balloon. Meteorograph No. 693 was hung about 80 feet below the balloon and No. 679, about 15 feet lower. The ascensional rate averaged 215 meters per minute up to 9 km. and 187 meters per minute to the highest altitude reached, viz, 17 km. Each of the records was computed independently and an inspection of the graphs (fig. 1) shows very close

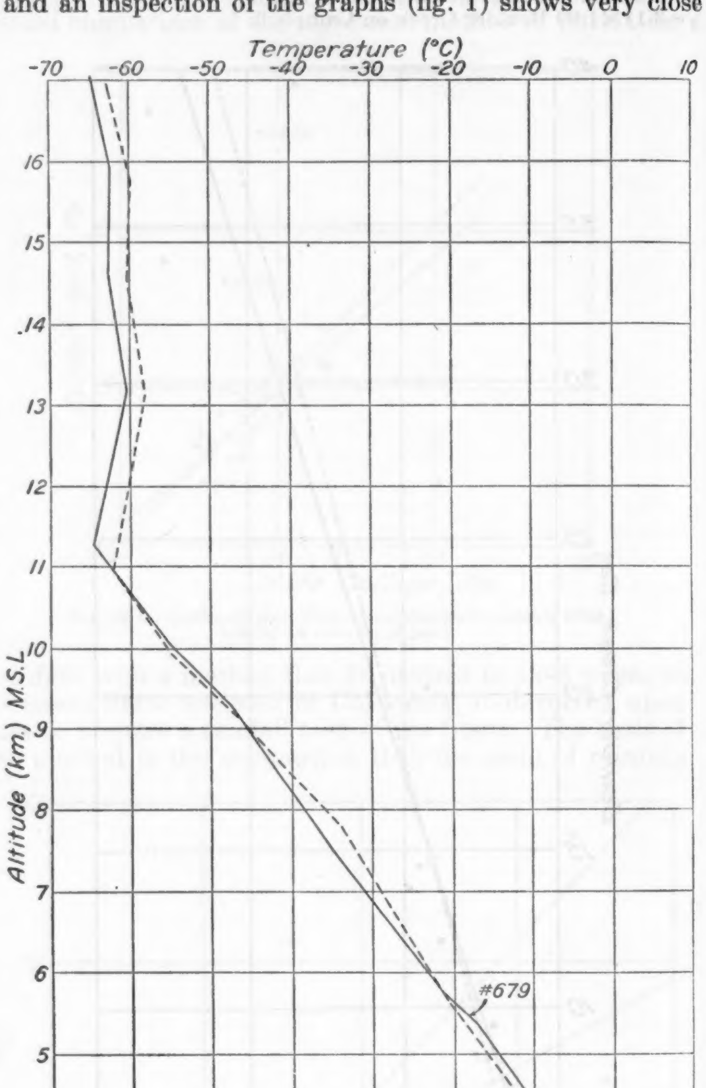


FIGURE 1.—Temperature-altitude graph of sounding-balloon observation using two meteorographs

agreement. It will be noted that at no point does the temperature recorded by both instruments differ by more than 3° C. Two marked inversion layers are shown between 1 and 2 km. and between 3 and 4 km., respectively. The height of the base of the stratosphere agrees to within 300 meters, or 3 per cent. The variations in lapse rate in the stratosphere are in striking agreement.

The relative humidities are likewise found to be in very close agreement. The greatest difference at any particular level was 10 per cent, while in most cases the difference was considerably less.

The general agreement found in the other cases where two instruments were attached to the same balloon was of the same order as that shown in Figure 1.

Figure 2 shows the temperature-altitude graphs of two observations made on February 2, with an interval of

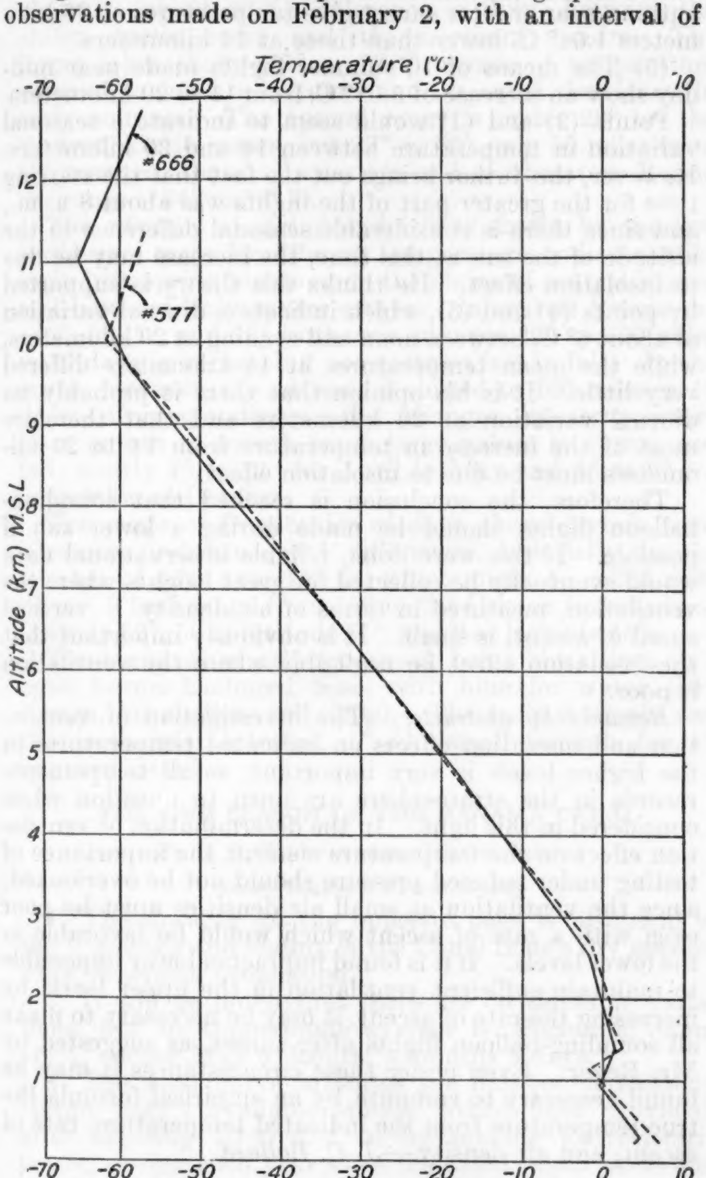


FIGURE 2.—Temperature-altitude graph of two sounding-balloon observations made 1 hour 23 minutes apart

1 hour and 23 minutes between them. The first balloon carrying meteorograph No. 577 was released at 3:55 p. m. (C. S. T.) (69 minutes before sunset), and the second balloon with meteorograph No. 666 at 5:18 p. m., or 14 minutes after sunset.

The agreement between the two graphs, it will be seen, is strikingly close up to the base of the stratosphere. The latter is found to be 1 km. higher at the time of the second observation. At least a part of this difference can be attributed to an actual change in atmospheric conditions since the descent portion of the record of the first observation indicated the stratosphere to be about 200 meters higher than on the ascent. A rise in the stratosphere would be expected from the fact that a high pressure area was moving in rapidly over Royal Center at the time.

It is evident that no vitiating effects from insolation resulted.

WHY THE READINGS OF THE MERCURIAL BAROMETER ARE CORRECTED FOR BOTH TEMPERATURE AND LATITUDE AND THE READINGS OF THE ANEROID BAROMETER LEFT UNCHANGED

By W. J. HUMPHREYS

[Weather Bureau, Washington]

It is an old story, of course, why we correct the readings of the mercurial barometer for both temperature and latitude and those of the aneroid for neither. Nevertheless, it may be worth telling again, since there is no convenient literature to which one can refer for an answer to this frequent question.

The aneroid barometer, a vacuum chamber with a flexible top attached to a movable index, responds only to changes in pressure, because the elastic reaction of its inclosed compressed spring that keeps the top from collapsing is practically independent of temperature, within the range of ordinary weather, and wholly independent of gravity. The *pressure* reading of the aneroid therefore needs no correction, save only that which might be necessary to make it agree with that of a standard instrument under the same conditions.

The mercurial barometer, on the other hand, a vertical glass tube sealed at the top, partly filled with mercury (vacuum above) and its open lower end dipping into a basin of mercury exposed to the air, balances, not the pressure of one fluid against a standard spring, as does the aneroid, but the pressures of two fluids against each other where they come together—in this case the pressure of the mercury against that of the air at their interface in the basin. Now, the pressure exerted by the mercury obviously increases directly with the vertical distance between its two surfaces; that is, with the "height" of the barometer, with the density of the mercury, and with the gravity pull per unit mass. But the density of the mercury varies with its temperature and the gravity pull with both latitude and height above sea level. Hence to find the *actual pressure* of the air from the current height of the barometer it is necessary to alter the reading to what it would be at some standard temperature (in addition to the similar correction for scale expansion) and standard gravity.

Why, though, this special interest in the pressure of the air rather than the mass of it overhead, for instance? Because the thing that makes the winds to blow, and thus effects weather transportation, is not primarily inequalities in the mass distribution of the air, but differences between the atmospheric pressures of neighboring places at the same level. This is why we commonly want the readings of our barometers to be in terms of actual pressures, or their equivalents, and that is why ordinarily the readings of the mercurial barometer are corrected for temperature and for latitude (gravity) and why the readings of the aneroid are left unchanged.

If, however, one had occasion to measure, or compare, the masses of air overhead at different places, as he might in the study of solar radiation, he would need to correct the readings of the aneroid barometer for latitude (gravity) and not the readings of the mercurial barometer.

A COMMON HUMIDITY ERROR

By W. J. HUMPHREYS

[Weather Bureau, Washington]

Many people who should know better seem to have surprisingly vague if not even confused ideas about humidity, and where there is much smoke there generally is some fire. Those who have to do with the measurement of humidity would insist, if questioned, that they know perfectly well what the terms "absolute humidity" and "relative humidity" properly mean. Perhaps they do; nevertheless many, if they should condescend to answer at all, would say, in substance, that absolute humidity is the mass of water vapor present per unit volume of the air, and relative humidity the ratio of the amount of water vapor present to the amount necessary to saturate the air at the same temperature.

That sounds familiar and orthodox, but it reveals confusion at best, for the air has nothing to do with either absolute humidity, properly defined as the mass of water vapor per unit volume (of space, not air), or relative humidity—the ratio of the mass of water vapor present per unit volume (of space) to that which would saturate a unit volume at the same temperature. Be certain not to add "and same pressure," which we sometimes hear, for that refers to the atmosphere, which, as just stated, has nothing to do with the phenomenon in question.

There is, however, one very useful humidity concept that does involve the air, namely, the mass of water vapor per unit mass of humid air. This is called "specific humidity."

But entirely apart from definitions we often see and hear expressions about the air taking up water vapor and about the great avidity of warm air for water vapor. Now, as a matter of fact, the air does not "take up" water vapor—it is not a sponge; and warm air has no avidity, chemical or other kind, for water vapor. All the air does in this connection is to slow down the rate of evaporation and diffusion. It is not the air but the space, air or no air substantially alike (a shade better without the air), that has the vapor capacity. Neither is it the temperature of the air but the temperature of the vapor (again air or no air) that determines the amount of water vapor per unit volume necessary to produce saturation.

Most of us say the air takes up water vapor. Let us forget it, if we can, and say space instead, as that is what we mean, if we understand the phenomenon aright.

TEMPERATURES IN THE HIGHER LAYERS OF THE STRATOSPHERE OVER LINDENBERG

By J. REGER

[Published in Beiträge zur Physik der freien Atmosphäre, XVII Band, Heft 2, pages 176-178. Translated and abstracted by J. C. Ballard, Aerological Division, Weather Bureau, Washington, D. C.]

In making this study of temperatures in the stratosphere the author has chosen a total of 123 sounding-balloon flights, 81 of which were made in the last four years and the remainder in earlier years. No flights in which the clock stopped prematurely, or which failed to reach a height of at least 17 kilometers, were used in the study, and since temperatures in only the upper levels were to be considered, the 14-kilometer altitude was chosen as the starting point.

Two tables of observed data were compiled and summarized. Some of the more interesting points brought out are as follows:

(1) The yearly means indicate an almost constant temperature from 14 to 16 kilometers and thereafter a slow increase, the mean values at 20 kilometers being 1.43° C. higher than at 14 kilometers.

(2) In winter there appears to be a mean decrease of 2.57° C. from 14 to 20 kilometers.

(3) In summer the mean values indicate the temperature at 20 kilometers to be 4.27° C. higher than at 14 kilometers.

(4) The means of seven flights made in summer and autumn near or after sunset give temperatures at 20 kilometers 1.04° C. lower than those at 14 kilometers.

(5) The means of 10 summer flights made near midday show an increase of 5.01° C. from 14 to 20 kilometers.

Points (2) and (3) would seem to indicate a seasonal variation in temperature between 14 and 20 kilometers. However, the author brings out the fact that the starting time for the greater part of the flights was about 8 a. m., and since there is considerable seasonal difference in the altitude of the sun at this time, the increase may be due to insolation effect. He thinks this theory is supported by points (4) and (5), which indicate a diurnal variation of about 6° C. between noon and evening at 20 kilometers, while the mean temperatures at 14 kilometers differed very little. It is his opinion that there is probably no diurnal variation at 20 kilometers and that therefore most of the increase in temperature from 14 to 20 kilometers must be due to insolation effect.

Therefore, the conclusion is reached that sounding-balloon flights should be made during a lower sun if possible. If this were done, reliable observational data would eventually be collected for great heights where the ventilation, measured in terms of air density × vertical speed of ascent, is small. It is obviously important that the insolation effect be negligible where the ventilation is poor.

Remarks by abstracter.—The investigation of ventilation and insolation effects on indicated temperatures in the higher levels is very important, as all temperature records in the stratosphere are open to question when considered in this light. In the determination of ventilation effect on the temperature element the importance of testing under reduced pressure should not be overlooked, since the ventilation at small air densities must be poor even with a rate of ascent which would be favorable in the lower levels. If it is found impracticable or impossible to maintain sufficient ventilation in the upper levels by increasing the rate of ascent, it may be necessary to make all sounding-balloon flights after sunset, as suggested by Mr. Reger. Even under these circumstances it may be found necessary to compute by an empirical formula the true temperature from the indicated temperature, rate of ascent, and air density.—*J. C. Ballard.*

RUBENSTEIN'S CLIMATIC ATLAS OF THE U. S. S. R.

Reviewed by C. F. BROOKS

The temperature section, Part I, Section I, of Eugenie Rubinstein's atlas of the climate of U. S. S. R.,[1] includes detailed monthly and annual maps of sea-level temperatures; mean annual range; the progress of the mean isotherms of −5°, 0°, 5°, 10°, and 15° C. in spring and fall by 10-day intervals; the number of days in the year with daily mean temperature over −5°, 0°, 5°, 10°, 15°; differences of the successive monthly means of temperature; and two plates including graphs of the monthly course of temperature at 28 stations.

[1] Eugenie Rubinstein, Klima der Union der Sozialistischen Sowjet-Republiken. Teil I. Die Lufttemperatur. Lieferung I. Monatsmittel der Lufttemperatur im Europäischen Teil der U. S. S. R., Geophysikalisches Zentral-Observatorium, Leningrad, 1927, 45 maps and diagrams, 40 by 52 cm.

The sea-level temperature maps show strikingly the gradients in temperature along the coasts, which in winter are particularly steep along the Murman coast and the northeastern shore of the Black Sea. In spring the contrasts in the south are much diminished, but in the northeast they are very great indeed, amounting in April to 12° C. in 7½° of latitude, or 1.6° C. (2.9° F.) per latitude degree. The summer months show striking contrast (about 6° C. difference in July) between the chilly Arctic coast and the northern tundra. The larger lakes show a 2° or 3° C. excess of temperature relative to land in autumn and an equal deficiency in early summer. The annual range is under 20° on the western Arctic coasts, but 27° to 30° only 50 miles from the northern shore. In eastern and southeastern Russia the range is 34° to 39° C.

The advance of spring and fall as shown by the five isothermal maps for different temperatures indicate strikingly how spring bursts upon the plains of central Russia and how suddenly winter sets in. In central Russia the −5°, 0°, 5°, and 10° isotherms advance 400 to 700 miles in 10 days in spring, but not quite so fast in fall. In the north, however, the advance is slowed to 100 miles in 10 days. Correspondingly, the changes in temperature from month to month reach large values in spring and fall, mostly 7° to 11° for April to May and 6° to 9° for September to October.

The maps of frequencies of days above certain temperatures indicate great differences, especially in the number of days over 15° C., which might be called mild days. These range from 150 in the Crimea to 100 about latitude 52°, 50 at latitude 61°, and 0 at latitude 65°.

The maps are clearly presented, being black lines on a light brown hachured base, with blue for water (two shades, for shallow and deep). The scale is ample and the isothermal interval, 1° C., small enough for all required detail.

THE DRY SEASON OF THE PANAMA CANAL

By R. Z. KIRKPATRICK, *Chief of Surveys*

[Balboa Heights, C. Z., May 25, 1931]

1. The drawing on the opposite page is historical of the beginning and ending of the Canal Zone's dry seasons since American occupation.

2. It will be noted that there are considerable variations; but an approximate average is: Beginning January 1, ending May 5; length, 4 months 5 days.

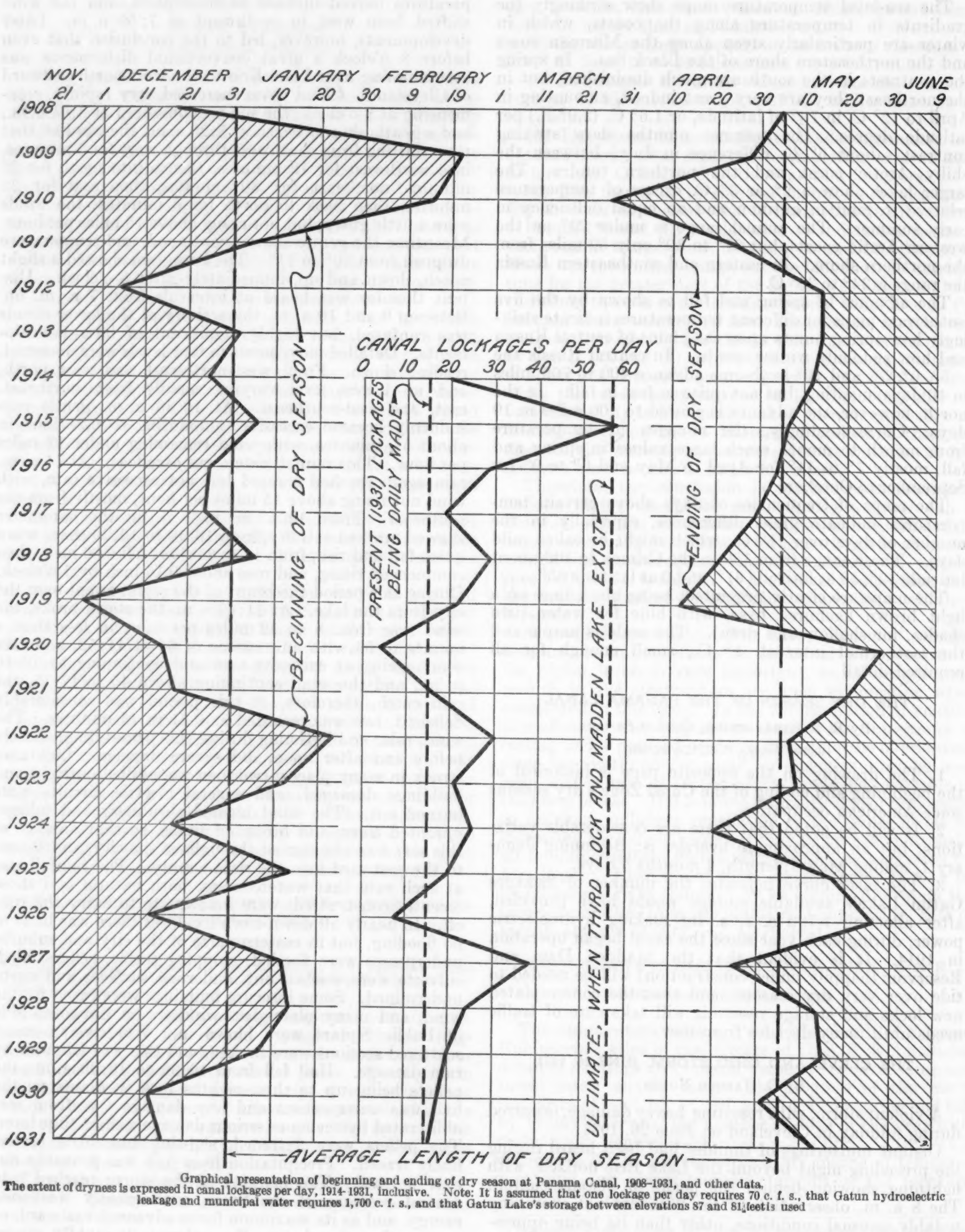
3. The inset curve indicates the number of lockages Gatun Lake's available storage would have provided, after allotting 1,700 c. f. s. for making hydroelectric power, during each year since the canal began operation in 1914. It is evident that the Madden Dam and Reservoir (happily under construction) will be needed to tide over very dry seasons, and that the contemplated new locks and storage reservoir will take care of traffic needs until many decades from now.

THE CLEVELAND, OHIO, STORM, JUNE 26, 1931

By G. HAROLD NOYES

A violent storm, with resulting heavy damage, occurred during midday in Cleveland on June 26, 1931.

Distant mutterings of thunder had been heard during the preceding night beyond the Lake Erie horizon, with lightning showing behind the peaks of distant cumuli. The 8 a. m. observation of the 26th did not show any notably unusual conditions, other than its being oppressively warm, with temperature of 80° and relative humidity of 74 per cent. With the rising of the sun, temperatures moved upward to correspond, and the wind shifted from west to southward at 7:55 a. m. Later developments, however, led to the conclusion that even before 8 o'clock a great convectional disturbance was accumulating over Lake Erie to the west-northwestward of Cleveland. Cloud cover increased very rapidly, commencing at 8 o'clock; the sun was obscured at 8:04 a. m., and a gentle shower began at 8:29 a. m., the wind at that time shifting from southwest through west for 3 minutes, into northwest for 12 minutes, thence into north for 20 minutes, northeast for 30 minutes, then east for 22 minutes, then back to north for 6 minutes; the winds were a little gusty, but not rising above 18 miles per hour. Meantime the gentle shower continued, and temperature dropped from 80° to 71°. The barogram showed a slight notch, down and up, immediately after 8 o'clock. Distant thunder was heard at intervals from 7 a. m. on. Between 9 and 10 a. m. the activity of the lower clouds was confused, but highly significant of later developments. Detailed movements in four levels were observed, reading down: From west-northwest and west, north, and at lowest level varying rapidly from northeast, east, and east-southeast. At 10:36 a. m. gentle rain suddenly became excessive, amounting to 0.28 inch in about 5½ minutes, with wind remaining under 12 miles per hour. This rainfall catch was excellent. At 11 a. m. rain again reached a rapid but not excessive rate, with wind not rising above 15 miles per hour, mostly from the southeast. From 10 a. m. to 1 p. m. the barometer showed marked activity; from 10:10 to 10:20 there was a quick fall and rise; from 11 to 11:30 it fell 0.06 inch, then commenced rising, and rose about 0.15 inch by 1 o'clock. During this period the brunt of the storm swept over the city from the lake. At 11:49 a. m. the storm broke, the wind rose from 8 to 12 miles per hour in less than a minute to 56, with an extreme of 64 at 11:52, and rain commencing at excessive rate and continuing to 12:10 p. m., and the wind continuing above 45 to 12:15, the rain catch, therefore, at this period was considerably deficient, but was recorded as 0.41 in 15 minutes. The wind, rain, and ligthning during this period, immediately before and after noon, did severe damage. Lightning struck in many places; two men were killed outright and buildings damaged, and several electric circuits were burned out. The wind blasted shrubbery and foliage, uprooted trees, and broke off limbs, so that damage of this sort was widespread throughout the city, and thence to the eastward into the next county. The rainfall was at such rate that watercourses, both natural and those recently constructed, were inadequate to carry the run-off. In nearly all down-town localities there was little or no flooding, but in eastern parts of the city and suburbs underpasses were flooded, stopping traffic, cellars filled, culverts were washed out, and road surfaces and curbs undermined. Some insecure buildings were razed by the wind, and many plate-glass windows on the south side of Public Square were blown in. Windows in many scattered sections were broken, and this was followed by rain damage. Hail fell from 10:36 to 10:39 a. m., the pellets being up to three-eighths inch in diameter; the hail was unimportant and any damage therefrom was obliterated by the more serious damage a short time later. The pellets were flattened, showing concentric layers, finely traced. Precipitation from hail was probably not over a trace. The margins of the storm reached into central portions of the State, with greatly weakened energy, and as its maximum focus advanced eastward, or east-southeastward, into Pennsylvania it rapidly diminished in force. It was felt only slightly at Erie, Pa., and



Graphical presentation of beginning and ending of dry season at Panama Canal, 1908–1931, and other data.
The extent of dryness is expressed in canal lockages per day, 1914–1931, inclusive. Note: It is assumed that one lockage per day requires 70 c. f. s., that Gatun hydroelectric leakage and municipal water requires 1,700 c. f. s., and that Gatun Lake's storage between elevations 87 and 81½ feet is used

little, if any, at Buffalo, N. Y. The western margins of the storm were near Sandusky, without damage.

Storm-sewer construction and catch basins in the areas immediately near Public Square appeared to be adequate for the run-off of this storm, but in the highlands and eastern suburbs, either the recent construction of water-courses and their resultant constriction is woefully undersized, or else the rain in that region was much greater than down town.

The loss, according to newspaper headlines, was in the millions.

A TORNADO IN NEW MEXICO[1]

By C. E. LINNEY

[Weather Bureau Office, Santa Fe, N. Mex.]

Just about a year after a destructive tornado struck Wagon Mound, Mora County, N. Mex., a second tornadic storm was observed to form on June 5, 1931, near the small village of French, Colfax County, about 35 miles northeast of Wagon Mound. This second tornado moved slowly east-southeast through a thinly settled country, doing but relatively little damage by reason of the sparsely settled country. It passed into and across Union County, doing quite a bit of damage to buildings and causing the death of a 3-year-old girl by an outbuilding crashing upon her. The property loss in the Gladstone district is estimated at about $1,500 and in the Barney and Sedan districts about $10,000 and $20,000, respectively.

The tornado was under observation during its entire course of about 90 miles. It dissipated after crossing the Texas border.

[1] Condensed from the original.—*Ed.*

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SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS DURING JUNE, 1931

By HERBERT H. KIMBALL, In Charge Solar Radiation Investigations

For a description of instruments employed and their exposures, the reader is referred to the January, 1931, REVIEW, page 41.

Table 1 shows that solar radiation intensities averaged above the normal intensities for June at Washington and below the June normals at Madison and Lincoln.

Table 2 shows an excess in the total radiation received on a horizontal surface as compared with the normal amount for June at Washington and New York; close to normal at Lincoln, Gainesville, and La Jolla; and a deficiency at all other stations for which normals have been computed.

TABLE 1.—*Solar radiation intensities during June, 1931*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	Sun's zenith distance										
	8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass									Local mean solar time
		A. M.					P. M.				
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
June 2	6.50				1.06	1.42					7.29
June 3	9.47					1.17	0.80				7.29
June 4	10.59			0.68	0.92	1.19					11.38
June 9	8.81		0.69	0.82	1.00						9.14
June 12	11.81				0.99						11.81
June 17	9.83		0.70	0.95	1.15	1.28					8.18
June 18	10.59		0.69	0.84	1.02	1.24					8.48
June 19	13.13		0.62	0.74	0.95	1.26	0.94				16.79
June 20	16.20			0.85	0.94	1.19					14.60
June 25	14.10					1.26					10.97
June 29	10.59		0.74	0.96	1.12	1.32	1.04				9.83
June 30	13.61			0.90	1.10	1.29					13.61
Means			0.69	0.84	1.02	1.26	0.93				
Departures			+0.03	+0.07	+0.09	+0.03	+0.02				

Madison, Wis.

Date	8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
June 8	6.76	0.81	0.87	0.99	1.17	1.30					6.02
June 16	9.47				1.15						10.97
June 18	11.38					1.24					17.37
June 24	14.10					1.19					19.89
June 25	18.59			0.81	1.00	1.20					20.57
June 26	18.59					1.22					20.57
June 27	19.23					1.17					19.23
June 29	19.89	0.48	0.57	0.73	0.91	1.18					18.59
June 30	17.96		0.61	0.75	0.88	1.19					16.20
Means		(0.64)	0.68	0.82	1.02	1.21					
Departures		−0.04	−0.16	−0.13	−0.08	−0.11					

Lincoln, Nebr.

Date	8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
June 3	12.68						1.11	0.93	0.71		11.81
June 8	10.59		0.59	0.73	0.90	1.19					12.68
June 16	15.11				0.96		0.98	0.78			13.13
June 17	15.65		0.59	0.73	0.95	1.21	1.06	0.89	0.69		15.65
June 18	16.79		0.80	0.93	1.04	1.21	1.02	0.78			16.20
June 23	14.10						1.06	0.89	0.76		16.20
June 24	15.11				1.13	1.30					15.11
June 25	16.20				1.09	1.35					15.11
June 26	16.20		0.78	0.92	1.11	1.32	1.03	0.86	0.73		15.11
June 27	17.37					1.29	1.01	0.82	0.69		14.10
June 29	16.79		0.64	0.78	1.00	1.25					15.65
June 30	15.65		0.78	0.91	1.09	1.34					14.10
Means			0.70	0.83	1.03	1.27	1.04	0.85	0.72		
Departures			−0.06	−0.09	−0.06	−0.07	−0.05	−0.05	−0.07		

[1] Extrapolated.

Skylight polarization measurements obtained on five days at Madison give a mean of 54 per cent, with a maximum of 61 per cent on the 8th. At Washington, measurements obtained on three days give a mean of 59 per cent, with a maximum of 64 per cent on the 4th. These are above the corresponding June averages for Washington. At Madison the values are slightly below the corresponding averages.

TABLE 2.—*Total solar radiation (direct+diffuse) received on a horizontal surface*

[Gram-calories per square centimeter]

Week beginning—	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Pittsburgh	Gainesville	Fresno	La Jolla	Miami	New Orleans
	AVERAGE DAILY TOTALS											
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
June 4	501	391	463	294	333	626	411	[1] 606	600	389	655	510
June 11	475	539	559	423	371	659	500	457	707	422	532	384
June 18	574	467	605	442	480	626	495	506	693	462	556	244
June 25	630	582	618	440	509	716	394	453	761	466	654	283
	DEPARTURES FROM WEEKLY NORMALS											
June 4	+17	−118	−66	−116	−65	−8	−38	+40	−82	−36		
June 11	−24	+42	+20	+17	−29	−2	+13	−43	+11	+14		
June 18	+89	−52	+41	+28	+70	−75	+2	+37	−26	+17		
June 25	+106	+41	+29	+9	+90	+15	−92	−38	+35	−9		
Excess or deficiency since first of year on July 1, 1931	+1,461	−4,291	+434	−1,323	−217	+554	−1,128	−534	−315	−2,674		

[1] 5-day mean.

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, Superintendent United States Naval Observatory. Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, Perkins, and Mount Wilson observatories. The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups is given for each day in the last column.]

Date	Eastern standard civil time		Heliographic			Area		Total area for each day
			Diff. long.	Longitude	Latitude	Spot	Group	
1931	*h*	*m*	°	°	°			
June 1 (Mount Wilson)	10	40	−57.0	106.5	+6.0		314	
			−51.0	112.5	+8.0	5		
			+30.0	193.5	−9.0		6	325
June 2 (Naval Observatory)	10	59	−40.0	110.2	+5.0		154	
			+40.0	190.2	−6.0		31	185
June 3 (Naval Observatory)	11	7	−26.0	110.9	+5.0		201	
			−20.5	116.4	−8.0	6		
			+56.0	192.9	−7.0		15	222
June 4 (Naval Observatory)	10	56	−12.5	111.2	+5.0		216	216
June 5 (Naval Observatory)	11	42	+2.5	112.6	+6.0		278	278
June 6 (Naval Observatory)	10	58	+16.0	113.3	+6.0		278	278
June 7 (Naval Observatory)	10	43	−20.0	64.2	−9.5	3		
			+31.0	115.2	+5.5		355	358
June 8 (Naval Observatory)	11	7	+47.0	117.7	+5.0		185	185
June 9 (Naval Observatory)	11	42	+17.0	74.1	+10.5		46	
			+54.0	111.1	+4.5		93	
			+70.0	127.1	+6.0		62	201
June 10 (Mount Wilson)	13	15	+20.0	63.1	−10.0	1		
			+31.0	74.1	+11.0		28	
			+70.0	113.1	+5.0		58	
			+85.0	128.1	+6.0	29		116
June 11 (Naval Observatory)	10	36	+43.0	74.3	+12.0		31	
			+80.0	111.3	+4.0	31		62
June 12 (Naval Observatory)	11	1	+55.0	72.8	+13.5	6		6
June 13 (Naval Observatory)	11	52	+8.5	12.6	−3.5		46	46
June 14 (Mount Wilson)	11	30	+78.0	69.0	−8.0		42	42
June 15 (Naval Observatory)	13	10		No spots.				
June 16 (Naval Observatory)	11	44		No spots.				
June 17 (Mount Wilson)	17	15	+26.0	334.2	−12.0	4		4
June 18 (Mount Wilson)	9	10	+35.0	334.4	−12.0	4		4
June 19 (Naval Observatory)	10	54	+2.5	287.7	−0.5		15	15
June 20 (Naval Observatory)	10	38		No spots.				
June 21 (Naval Observatory)	10	51		No spots.				
June 22 (Naval Observatory)	11	27		No spots.				
June 23 (Naval Observatory)	10	59		No spots.				
June 24 (Naval Observatory)	10	42		No spots.				
June 25 (Naval Observatory)	10	47	+2.0	207.9	−1.5		31	31
June 26 (Mount Wilson)	18	15	−65.0	123.5	+3.0	7		7
June 27 (Naval Observatory)	10	47	−30.0	149.4	−2.5	9		9
June 28 (Naval Observatory)	10	55	−18.0	148.1	−2.5	12		12
June 29 (Naval Observatory)	11	3	−75.0	77.8	+6.0		123	
			−72.0	80.8	−10.0		62	185
June 30 (Naval Observatory)	10	54	−62.5	77.1	+6.0		108	
			−59.0	80.6	−9.5	62		170
Mean daily area for June								99

AEROLOGICAL OBSERVATIONS

[The Aerological Division, W. R. GREGG in Charge]

By L. T. SAMUELS

Table 1 contains data for only three stations, aerological observations having been discontinued at Broken Arrow, Okla., and Groesbeck, Tex. It will be noted that free-air temperatures were above normal at the two northern stations, viz., Ellendale and Royal Center, and below normal at Due West. The positive departures increased with altitude, being greatest between 2,000 and 3,000 meters elevation.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during June, 1931*

TEMPERATURE (°C.)

Altitude (meters) m. s. l.	Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Royal Center, Ind. (225 meters)	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Surface	24.5	−0.9	21.4	+2.7	23.0	+1.2
500	21.8	−0.7	21.0	+2.7	21.4	+2.5
1,000	19.6	+0.2	19.4	+4.1	19.5	+3.9
1,500	16.0	0.0	17.8	+5.1	16.6	+3.8
2,000	12.5	−0.2	15.1	+5.3	14.0	+3.8
2,500	9.1	−0.5	11.8	+4.9	11.6	+4.1
3,000	5.6	−0.9	8.4	+4.3	8.9	+4.1
4,000	−2.4	−2.3	2.2	+3.8	2.7	+2.9
5,000	−8.4	−2.3	−4.1	+3.4	−3.1	+3.6

RELATIVE HUMIDITY (%)

Altitude (meters) m. s. l.	Due West Mean	Departure	Ellendale Mean	Departure	Royal Center Mean	Departure
Surface	63	−2	66	−4	71	+5
500	65	−2	65	−4	69	+1
1,000	60	−7	55	−12	65	−4
1,500	63	−6	51	−13	65	−2
2,000	64	−6	50	−12	64	+2
2,500	62	−8	52	−9	62	+6
3,000	61	−7	54	−3	61	+9
4,000	60	0	55	+5	62	+21
5,000	55	0	61	+11	53	+2

VAPOR PRESSURE (*mb.*)

Altitude (meters) m. s. l.	Due West Mean	Departure	Ellendale Mean	Departure	Royal Center Mean	Departure
Surface	19.74	−0.86	16.82	+1.53	20.54	+3.22
500	17.22	−0.83	16.30	+1.48	17.96	+3.08
1,000	13.98	−0.99	12.20	+0.47	14.96	+2.47
1,500	11.73	−0.81	10.05	+0.62	12.78	+2.51
2,000	9.47	−0.71	8.41	+0.81	10.74	+2.84
2,500	7.21	−0.99	7.17	+0.91	8.86	+3.10
3,000	5.65	−0.77	6.11	+1.28	7.39	+3.10
4,000	3.25	−0.28	4.14	+1.03	5.39	+3.21
5,000	2.32	−0.28	2.76	+0.40	3.60	+1.87

The relative humidity departures were mostly small and negative except at Royal Center, where positive departures occurred with positive temperature departures. This condition is evidently significant in connection with the large amount of precipitation for the month at Royal Center, viz., 8.97 inches, which exceeded all previous amounts for June since the establishment of the station in 1918.

Vapor pressure departures were of the same sign as those for temperature, with the largest departures occurring at Royal Center.

Conspicuous in Table 2 is the low relative humidity at 2,000 and 3,000 meters at San Diego as compared with the other stations. This condition is characteristic of the southwestern part of the country and is probably a consequence of air originating over Mexico.

A noticeable feature of Table 3 is the southwesterly component in the free-air resultant winds over the western part of the country as compared with the northwesterly component over the eastern section.

TABLE 2.—*Free-air data obtained by airplanes at naval air stations during June, 1931*

Altitude (meters) m. s. l.	Temperature (°C.)				Relative humidity (%)			
	Hampton Roads, Va.	Pensacola, Florida	San Diego, Calif.	Washington, D. C.	Hampton Roads, Va.	Pensacola, Florida	San Diego Calif.	Washington, D. C.
Surface	22.1	24.3	21.4	21.3	71	82	65	67
500	18.7	22.8	17.7	19.8	66	71	72	58
1,000	16.1	20.2	16.5	17.6	62	62	62	59
2,000	9.7	14.0	14.1	12.3	62	61	36	57
3,000	4.1	8.6	9.0	7.1	62	55	27	51
4,000				0.2				56

TABLE 3.—*Observations by means of kites, captive and limited height sounding balloons during June, 1931*

	Broken Arrow, Okla.	Due West, S. C.	Ellendale, N. Dak.	Royal Center, Ind.
Mean altitudes (meters), M. S. L., reached during month	2,664	2,852	3,387	3,955
Maximum altitude (meters), M. S. L., reached and date	[1] 4,039	[1] 5,090	[1] 5,197	[1] 9,343
Number of flights made	[2] 7	32	30	33
Number of days on which flights were made	[2] 7	28	28	30

[1] Limited-height sounding balloon observation.
[2] Covers period from June 1 to 7, inclusive, only.

In addition to the above, there were approximately 180 pilot-balloon observations made daily at 60 Weather Bureau stations in the United States.

TABLE 4.—*Free-air resultant winds (meters per second) based on pilot balloon observations made near 7 a. m. (E. S. T.) during June, 1931*

Altitude (meters) m. s. l.	Albuquerque, N. Mex. (1,528 meters) Direction	Velocity	Brownsville, Tex. (12 meters) Direction	Velocity	Burlington, Vt. (132 meters) Direction	Velocity	Cheyenne, Wyo. (1,873 meters) Direction	Velocity	Chicago, Ill. (198 meters) Direction	Velocity	Cleveland, Ohio (245 meters) Direction	Velocity
	°		°		°		°		°		°	
Surface	N 31 E	0.6	S 42 E	1.5	S 5 E	1.0	N 85 W	2.5	S 4 W	1.0	S 5 W	0.9
500			S 24 E	9.2	S 75 W	1.9			S 52 W	3.7	S 53 W	1.5
1,000			S 18 E	7.8	N 33 W	3.7			S 89 W	5.3	N 74 W	2.2
1,500			S 19 E	5.8	N 35 W	4.8			N 86 W	6.6	N 77 W	3.5
2,000	S 30 E	1.1	S 21 E	5.1	N 27 W	6.2	S 84 W	4.5	N 78 W	6.4	N 66 W	5.4
2,500	S 49 W	2.0	S 30 E	3.7	N 33 W	8.3	S 83 W	5.4	N 76 W	5.9	N 60 W	5.0
3,000	S 78 W	3.1	S 66 E	2.7	N 32 W	8.7	N 77 W	6.2	N 87 W	6.4	N 66 W	5.1
4,000	S 71 W	4.0	S 61 E	1.4	N 42 W	9.4	N 70 W	7.8	N 51 W	11.5	N 52 W	5.8
5,000	S 33 W	3.4	N 7 E	1.8			N 83 W	7.5				

Altitude (meters) m. s. l.	Dallas, Tex. (154 meters) Direction	Velocity	Due West, S. C. (217 meters) Direction	Velocity	Ellendale, N. Dak. (444 meters) Direction	Velocity	Havre, Mont. (762 meters) Direction	Velocity	Jacksonville, Fla. (14 meters) Direction	Velocity	Key West, Fla. (11 meters) Direction	Velocity
	°		°		°		°		°		°	
Surface	S 32 E	2.5	W	0.2	S 20 W	0.4	S 68 W	1.4	S 47 W	0.5	N 84 E	1.8
500	S 15 W	9.0	S 79 W	2.2	S 19 W	1.2			S 76 W	2.8	S 86 E	4.5
1,000	S 18 W	7.4	N 70 W	2.4	S 47 W	4.4	S 72 W	3.2	N 81 W	2.3	S 80 E	3.4
1,500	S 24 W	4.6	N 64 W	3.1	S 67 W	4.5	N 89 W	5.8	N 35 W	1.6	S 63 E	2.6
2,000	S 22 W	3.1	N 65 W	4.3	S 63 W	3.9	S 83 W	6.0	N 6 E	2.2	S 27 E	1.6
2,500	S 16 W	2.7	N 64 W	4.3	S 68 W	4.8	S 72 W	6.3	N 11 E	2.2	S 15 E	1.6
3,000	S 15 W	1.5	N 40 W	4.5	N 84 W	5.5	S 75 W	7.3	N 20 E	1.9	S 25 E	1.0
4,000	N 58 W	0.8	N 44 W	6.6	N 84 W	8.9	S 71 W	8.2	N 29 W	2.8	S 38 W	1.1
5,000	N 85 E	1.5	N 36 W	5.7	N 82 W	12.0	S 82 W	10.7	N 38 W	3.6	S 65 W	1.7

TABLE 4.—*Free-air resultant winds (meters per second) based on pilot balloon observations made near 7 a. m. (E. S. T.) during June, 1931*—Continued

Altitude (meters) m. s. l.	Los Angeles, Calif. (127 meters)		Medford, Oreg. (410 meters)		Memphis, Tenn. (145 meters)		New Orleans, La. (25 meters)		Oakland, Calif. (8 meters)		Oklahoma City, Okla. (392 meters)		Omaha, Nebr. (299 meters)		Phoenix, Ariz. (356 meters)		Salt Lake City, Utah (1,294 meters)		Sault Ste. Marie, Mich. (198 meters)		Seattle, Wash. (14 meters)		Washington, D. C. (10 meters)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	S 84 E	0.6	N 61 W	0.4	S 6 W	1.1	N 6 E	0.3	S 78 W	1.5	S 1 W	2.9	S 32 E	2.3	N 84 E	1.2	S 22 E	2.3	S 78 E	0.8	S 39 E	1.1	N 20 W	1.0
500	S 59 E	1.2	N 79 W	0.5	S 71 W	3.2	N 71 W	0.9	N 83 W	3.1	S 13 W	6.6	S 4 W	5.4	N 88 W	0.3	---	---	S 10 E	1.8	S 13 W	2.5	N 46 W	3.8
1,000	N 46 W	0.9	N 88 W	1.0	S 85 W	3.8	S 36 E	1.5	N 63 W	5.3	S 33 W	10.8	S 44 W	9.0	S 60 W	1.9	---	---	S 56 W	3.4	S 29 W	3.2	N 44 W	4.6
1,500	N 53 W	2.1	S 31 W	1.0	S 74 W	4.0	S 40 E	2.0	N 52 W	4.1	S 40 W	8.5	S 50 W	7.9	S 5 W	1.2	S 13 E	5.2	S 74 W	3.0	S 42 W	3.9	N 52 W	5.8
2,000	S 83 W	2.4	S 33 W	1.8	S 79 W	4.6	S 70 E	1.8	N 77 W	4.6	S 41 W	6.5	S 57 W	6.0	S 9 E	3.0	S 4 W	5.8	S 86 W	3.6	S 41 W	4.6	N 56 W	6.6
2,500	S 19 W	2.7	S 51 W	4.2	S 59 W	4.7	S 76 E	1.4	N 88 W	4.1	S 54 W	3.8	S 51 W	6.2	S 1 W	4.8	S 30 W	6.5	N 82 W	4.6	S 41 W	3.6	N 54 W	6.9
3,000	S 18 W	3.4	S 48 W	6.0	S 47 W	3.7	S 74 E	1.2	S 78 W	4.7	S 58 W	2.8	S 49 W	4.8	S 16 W	6.4	S 48 W	6.5	N 81 W	6.5	S 14 W	4.6	N 50 W	7.3
4,000	---	---	S 53 W	6.8	---	---	N 12 E	1.9	---	---	N 55 W	1.2	S 71 W	3.9	S 29 W	7.5	S 45 W	6.9	N 83 W	9.2	---	---	N 22 W	9.5
5,000	---	---	---	---	---	---	N 86 W	0.9	---	---	---	---	N 63 W	5.6	S 18 W	6.6	S 54 W	11.4	N 65 W	15.4	---	---	---	---

WEATHER IN THE UNITED STATES

[Climatological Division, Oliver L. Fassig in Charge]

THE WEATHER ELEMENTS

By M. C. BENNETT

GENERAL SUMMARY

June as a whole was abnormally warm in the interior and Northwestern States, while moderate temperatures prevailed in much of the South and Atlantic areas. From Oklahoma, Missouri, and Illinois northward and northwestward the monthly mean temperature averaged from 5° to 9° above the normal, the last week being abnormally warm, with the highest weekly mean temperatures of record for June over large areas. The month was likewise abnormally warm along the south Pacific coast, while generally moderate temperatures for the season prevailed in the north Pacific districts.

The precipitation for the month was rather unevenly distributed, with less than the normal over large areas. The Northeast, much of the Lake region, southern Texas, and the Rio Grande Valley received generous to heavy rainfall for the season, and more than normal was received in much of the Pacific region from central California northward. Elsewhere the precipitation was below normal, especially in portions of the Southeast and Northwest. From 10 to 25 per cent of normal was recorded in northern Alabama and Georgia, eastern Tennessee, and portions of the Carolinas, while in portions of southern Idaho only about one-tenth of the normal was received.

TEMPERATURE

From the beginning of the month until a little after the middle the temperature presented no features deserving special notice, although in the far Northwest readings were usually several degrees higher than normal, while comparatively cool weather was noted at times in several portions of the eastern half of the country. This tendency to temperatures below normal was most persistent in some parts of the Lake region and in coast districts between the Rio Grande and Chesapeake Bay.

After the 17th marked heat set in over the southern Plains and the central valleys and prevailed during the remainder of the month, generally increasing in intensity and extending until practically all States from the Rocky Mountain foothills to the Appalachians were under its sway. The Atlantic States were somewhat affected by hot weather, yet mainly were not much warmer than normal during these final two weeks of June, while some districts west of the Continental Divide were experiencing cool weather, particularly the northwesternmost States, during the last week.

The month averaged warmer than normal almost throughout the country, a few areas near Lake Ontario or along the Atlantic or Gulf coast averaging slightly cooler than normal, also much of the far Southwest and part of the State of Washington. From the northern and middle Rocky Mountains eastward to the upper Lakes and the lower Ohio Valley the month averaged at least 3° above normal, and over the northern half of the Plains from 6° to 9° above. The mean temperature was the highest of June record at numerous stations in the northern and middle Plains and the upper Mississippi Valley, while as far to southeastward as Chattanooga, Tenn., it was but slightly below the June record.

The highest marks noted during the last 10 days of June became the record temperatures for all Junes at many stations in the central part of the country.

In general, 100° was reached or passed in every State, save a few small Northeastern States, while some Central Valley States noted marks of 107° to 109°, and South Dakota, 115°. The highest mark reported anywhere in the country was 119° in Arizona. Usually the highest readings occurred during the last three days, but in parts of the upper Ohio Valley and Middle Atlantic States, also the southern Plains, about the 20th, and in the far West on various dates.

The lowest readings of June varied from 48° in several Gulf States to 16° in Oregon, the latter at a high mountain station. Except in the Pacific and northern Rocky Mountain States they usually ocurred during the first 10 days of the month.

PRECIPITATION

In the middle and northern portions of the country between the Rocky Mountains and the Mississippi River the important rains of June occurred at various times in the different States, except the closing week was mainly very dry. To eastward the weeks were about equal in the matter of rains, when the whole area is considered, save the second week which brought little, except in the Lake Superior region and close to the Atlantic coast.

The southeastern and south-central portions of the country had generally scanty rainfall compared with normal, and what occurred fell mainly during the second and third weeks, save that Oklahoma and the Carolina coast had moderate supplies during the first week and

southwestern Texas had decidedly heavy rains during the last week.

In the Pacific Northwest there was practically no rain until the 9th, but afterwards considerable amounts were received, the falls about the 16th being especially liberal and widespread. The San Joaquin Valley in California received considerable rainfall for the time of the year, about the 7th.

Over two-thirds of the States failed to receive their June normal amounts of rainfall. The exceptions were New Jersey and the New England States, Michigan and Wisconsin, and the Pacific States, with Arizona. Massachusetts received more than twice its normal, on the average, Oregon an inch more than normal, and Washington over 2 inches more than normal.

In the States of the western half, which have not been accounted for above, there was usually from a half to four-fifths of the normal June rainfall, but southern Idaho and northern Utah had remarkably little, while the middle and lower Rio Grande Valley had more than normal.

In the lower Mississippi Valley and to eastward decided shortages were noted, especially in northern Georgia and districts adjacent. From Missouri and Iowa eastward the quantities were usually not much below normal, and they generally exceeded the normal in northwestern Indiana and the upper Ohio Valley.

In western Washington 16.39 inches was measured at one station, the largest in the United States proper. In the South, Runge, Tex., measured 12.58 inches, while the East was led by 11.33 inches at a station in Putnam County, N. Y.

SNOWFALL

Scarcely any snowfall was reported from the elevated stations of the Western States, save that a few points in the Sierra Nevada Mountains had measurable falls. It is stated that the northern part of Flathead County, Mont., had an unusually heavy June snowstorm on the 16th and 17th.

SUNSHINE AND RELATIVE HUMIDITY

More than the average amount of sunshine was received from the eastern foothills of the Rocky Mountains eastward to the Atlantic, except in portions of the Lake region, the northern Ohio Valley, the far Northeast, and the western Gulf States. More than normal was likewise received in much of California and southeastern Oregon. Elsewhere it was generally near the average.

The relative humidity was above the normal throughout portions of the Pacific States, the southern plateau, and the southern portion of Texas, the upper Lake region, portions of the Ohio Valley and northern Appalachian Mountains and the New England States. However, in all cases the departures were but slightly above normal. Elsewhere the humidity was generally below normal with minus departures rather pronounced in the southern Appalachian region, the southern portions of the Great Plains, and the northern Rocky Mountains.

SEVERE LOCAL STORMS, JUNE, 1931

The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards [1]	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Olar (near), S. C	1	5:30 p. m.	4 mi.		$65,000	Hail	Severe crop damage; path, 7 miles	Official, U. S. Weather Bureau.
Billings to Ballantine, Mont	2	4-5 p. m.			25,000	Tornadic wind	Damage chiefly to oil refinery	Do.
Bridgewater (near), S. Dak	2	5:30 p. m.	16		500	Small tornado	Cabins destroyed	Do.
Grand Rapids (near), Mich	3					Thunderstorms	Power and telephone service interrupted; several buildings damaged.	Do.
Warren, Ill	3					Wind	Farm buildings and trees damaged	Do.
Lafayette County, Wis. (southern).	4		4 mi.		4,000	Thundersquall	Several barns damaged or demolished; path, 8 miles long.	Do.
Northboro, Iowa (southwest of)	4				875	Tornado and hail	Minor damage to property; poultry killed	Do.
Waushara County, Wis. (eastern)	4	11 p. m.	3 mi.		3,000	Thundersquall	Buildings damaged	Do.
Apple River, Ill., and vicinity	5	12:30 a. m.	4 mi.			Severe wind	Property damaged; several thousand dollars	Do.
Union County, Iowa	5	3-7 a. m.			2,000	Rain and hail	Truck gardens hurt	Do.
Decatur County, Iowa	5	5 a. m.	3 mi.		4,200	Wind, rain and floods.	Buildings and crops damaged; path, 6 miles	Do.
French (near) to Sedan, N. Mex.	5	12:15-6 p. m.		1	30,000	Tornado and hail	Livestock killed; buildings and orchards wrecked; path, 90 miles long.	Do.
Harper County, Okla. (northern).	5	4 p. m.	2 mi.		160,000	Hail	Damage chiefly to crops; path, 24 miles long	Do.
Logan and Thomas Counties, Kans.	5	6 p. m.	1,760		30,000	do	Wheat total loss in places; path, 30 miles long	Do.
Freedom (near), Okla	5	6:20 p. m.			15,000	do	Corps damaged	Do.
Clark County, Iowa	6	2-7 p. m.			3,000	Wind and hail	Greenhouses and crops damaged; path, 12 miles long.	Do.
Knox and Cedar Counties, Nebr.	6	4 p. m.	Up to 2 mi.		65,000	Tornado	Farm buildings demolished; crops injured 10 per cent in places; path, 18 miles long.	Do. Do.
Indiana County, Pa. (central)	6	4-5 p. m.	1,760		10,000	Hail and wind	Many buildings unroofed; orchards and crops badly damaged.	Do.
Waterville, Kans. (5 miles southwest).	6	4:30 p. m.	300		5,000	Small tornado	Farm buildings wrecked; path, 900 yards long.	Do.
Salina, Kans., and vicinity	6	5 p. m.	6 mi.		10,000	Hail	Much damage to greenhouses and wheat; path, 15 miles long.	Do.
Lincoln, Nebr	6	5:45 p. m.	2 mi.		80,000	do	Chief damage to roofs, windows and greenhouses; path, 2 miles long.	Do.
Elk (near), Kansas	6	6 p. m.	300		3,000	Tornado and hail	Farm property damaged; path, 10 miles long	Do.
Wilson County, Kans	6	6-7 p. m.			14,000	Hail	Character of damage not reported	Do.
Olathe, Kans., and vicinity	6	7 p. m.	1,760		60,000	Hail and wind	Chief damage to wheat and oats; trees stripped; path 10 miles long.	Do.
Shattuck, Okla	6	7 p. m.	3 mi.			do	Heavy crop loss; path, 6 miles long	Do.
Eureka (near)	6	7:30 p. m.	17		100	Small tornado	Small farm buildings damaged; path 1,300 yards long.	Do.
Independence, Kans., and vicinity.	6	8:30 p. m.	900		1,000	Hail	Greenhouses and fruit damaged; path 1 mile long.	Do.
Greensburg, Pa., and vicinity	6	10 p. m.	880		5,000	Wind	Several farm buildings demolished	Do.
Pennsylvania (northeastern)	6	P. m.			250,000	Wind, electrical, hail and rain.	Extensive damage to buildings and other property.	Do.
Evansville, Ind., and vicinity	6					Thunderstorm and wind.	Some delay caused by flooding of streets and sewers; other property damaged.	Do.
Missouri (northwestern)	6		½-4 mi.		75,000	Hail, wind, and rain.	Orchards and field crops severely damaged; windows broken.	Do.
Mounds, Ill., and vicinity	6-7		3 mi.		10,850	Hail	Fruits and vegetables injured 25 to 90 per cent; roofs, auto tops, and tents pierced; path 5 miles long.	Do.

[1] "Mi" signifies miles instead of yards.

Severe local storms, June, 1931—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Pennsylvania (South-central)	7				$100,000	Electrical, wind, and hail.	Buildings unroofed; trees uprooted; stock killed.	Official, U. S. Weather Bureau.
Frederick and Carroll Counties, Md.	7	3:30 p. m.				Wind	Several small buildings unroofed; many trees and a few poles blown down.	Do.
Chickasaw County, Iowa	8	2 a m.	1,760		2,000	Hail	Crops injured; path 4 miles long.	Do.
Davidson, Okla.	8	5 p. m.	1,760		2,000	do	Cotton crop injured; path 2 miles.	Do.
Duke (near), Okla.	9	6 p. m.	2.5 mi.		25,000	do	Chief damage to crops; path 4 miles long.	Do.
Clark County, Kans	10	4 p. m.	3 mi.		15,000	do	Wheat loss 50 to 100 per cent; windows and autos damaged; path 10 miles long.	Do.
Reno County, Kans	10	6:30 p. m.			50,000	do	Farm property severely damaged.	Do.
Union (near), Okla.	10	7 p. m.			25,500	do	Considerable crop loss; minor property damage.	Do.
Glasco (near), Kans	10	8 p. m.			1,000	Small tornado	Residence and implement shed wrecked; path 4 miles long.	Do.
Concordia to Belleville, Kans	10	8:30 p. m.			500	Violent wind and probably small tornado.	Number of small buildings unroofed.	Do.
Mayfield, Kans., and vicinity	10	P. m.	3 mi.			Hail	Wheat total loss; other crops badly injured; path 7 miles long.	Do.
Pryor, Okla., and vicinity	11	2:30 p. m.	2 mi.		12,000	do	Chief damage to crops; path 8 miles long.	Do.
Rochelle (near), Tex	11	4 p. m.	150			Tornado	4 persons injured; character of damage not reported.	Do.
San Saba (near), Tex	11	5 p. m.	2,640			Hail	Crops damaged; livestock killed.	Do.
Greenville, Commerce, and Cooper, Tex.	11	6:45 p. m.	12 mi.			Wind	Buildings unroofed; chimneys, poles, and trees blown down.	Do.
Deport, Tex	11	8 p. m.			10,000	do	Buildings damaged.	Do.
Princeton (near), Tex	11	8:30 p. m.	1,320		1,000	Wind and hail	Some damage to buildings and crops.	Do.
Boone County, Nebr. (western)	12	3 p. m.	1,760		9,000	Hail	Considerable crop damage in places.	Do.
Brownfield (near), Tex	12	7 p. m.	2 mi.		5,000	do	Crops ruined.	Do.
Kossuth County, Iowa	12	10 p. m.	4 mi.		4,000	Wind	Windmills and buildings damaged; path, 6 miles long.	Do.
Tupelo (near), Miss	12	11 p. m.				Probably tornado	Crops and trees damaged.	Do.
Hamlin (near), Tex	12	P. m.	3 mi.			Hail	Crops ruined.	Do.
Princeton, Ind	12				3,000	Wind	Buildings damaged.	Do.
Sherman County, Kans. (eastern).	12	P. m.			6,000	Hail	Wheat injured.	Do.
Duplin County, N. C. (northwestern).	13	5 p. m.	880		100,000	Hail and wind	Damage chiefly to crops; 4 barns and other small buildings blown down.	Do.
Albemarle County, Va. (southwestern).	13	8:30-11:30 p. m.	½-6 mi.		30,000	Hail	Fruits, chiefly apples, damaged.	Do.
Garden City, Kans	13					do	4,000 acres of wheat damaged.	Do.
South Byron, N. Y	14	3-5 p. m.	2,640		10,000	do	Peas and tomatoes damaged.	Do.
Rush Center and vicinity, Kans.	14	4-5 p. m.	2 mi.		10,000	do	Wheat damaged 40 per cent; path, 5 miles long.	Do.
Amarillo, Tex. (east of)	14	6 p. m.			10,000	do	Considerable crop damage.	Do.
Spearman (near), Tex	14	6:30 p. m.	2 mi.		50,000	do	Much loss to crops.	Do.
Rice and Reno Counties, Kans	14	7-9 p. m.	4 mi.		600,000	do	Heavy damage to wheat, apples, and gardens; windows and auto tops pierced; path, 35 miles long.	Do.
Harvey County, Kans	14	9-9:30 p.m.	2 mi.		70,000	do	Heavy damage to automobiles, roofs, and windows; traffic delayed; path, 12 miles long.	Do.
Hancock County, Ga. (southern)	14				2,000	do	Crops injured.	Do.
Buffalo, N. Y	14					Wind and thunderstorm.	House blown down and large smokestack damaged.	Do.
Waycross, Ga	14				5,000	Wind	Church demolished and several roofs blown off; 2 persons injured.	Do.
Bickleton, Wash	15	6:30 p. m.	1,760		5,000	Hail	Grains, gardens, shrubbery, and windows damaged.	Do.
Montezuma, Ga	15					Wind	Small barns, tenant house, and church wrecked.	Do.
Trenton, S. C.	15				6,000	Thunderstorm	Cotton gin burned.	Do.
Montana (northwestern counties)	16				16,300	Hail	Damage chiefly to crops.	Do.
Dallas, Tex	17	5:10 p. m.			60,000	Thunderstorm	Oil tank struck by lightning and burned.	Do.
Doretta, Mont	17	Noon	2 mi.			Hail	Considerable damage, character not reported.	Do.
Clay and Chickasaw Counties, Iowa.	18	11:30 p. m. -midnight.			22,000	Wind	Buildings wrecked.	Do.
Winneshiek, Wayne, and Benton Counties, Iowa.	19	A. m.			14,500	do	Buildings and crops damaged.	Do.
Wessington (near), S. Dak	19	4:30 p. m.	880		32,500	Tornado and hail	Farm buildings wrecked.	Do.
Davison to Lake County, S. Dak.	19	7 p. m.	10 mi.		12,000	Wind and hail	Windmills blown down; crops and farm buildings damaged.	Do.
Kossuth County, Iowa	19	10 p. m.			500	Tornado	Buildings damaged.	Do.
Mallard (near), Iowa	19	do			7,300	do	Damage chiefly to farm property; path, 1 mile long.	Do.
Sioux Rapids (near), Iowa	19	do	67			Tornado and wind	Property on 5 farms damaged; path, 5 miles long.	Do.
Hayfield (near), Iowa	19	10:30 p. m.		1	24,000	do	Trees, buildings, and telephone equipment damaged; 4 persons injured; path, 6 miles long.	Do.
Deerfield (near) to Alta Vista, Iowa.	19	11-11:30 p. m.			70,000	do	Buildings and crops heavily damaged; livestock killed or injured.	Do.
Waterloo, Iowa	19	11:40 p. m.	267		8,000	Tornado	Character of property damaged not reported; path, 2 miles.	Do.
Garwin (near), Iowa	19	11:45 p. m.			1,200	do	Buildings and trees damaged; path, 6 miles long.	Do.
Carroll and Cherokee Counties, Iowa.	19				45,000	Wind and hail	Considerable damage to crops.	Do.
Lyndonville and Wilson, N. Y	19				14,000	Electrical	Several buildings burned.	Do.
Whitehall (near) and Neilsville (near), Wis.	19				3,000	Thunderstorm and hail.	Several barns and other farm buildings damaged.	Do.
Jerico, Iowa (north of)	20	12:15 p. m.			13,000	Tornado and wind.	Buildings and crops damaged; path, 7 miles long.	Do.
Walthill, Nebr. (4 miles southwest).	20	4 p. m.	880			Hail	Crops considerably damaged; path, 1 mile long.	Do.
Cass, Pottawattamie, Shelby, and Humboldt Counties, Iowa.	20	P. m.			208,000	Wind and hail	Heavy crop loss; buildings damaged.	Do.
Central and southern counties, New York.	20	do		1		Severe electrical and wind.	Many trees blown down; several barns wrecked; much damage to roofs, buildings, and wires; livestock killed.	Do.
Green and Sac counties, Iowa	20				6,000	Hail	Crops damaged.	Do.
Guthrie, Harrison, Hancock, Linn, and Winneshiek Counties, Iowa.	20				24,000	Wind	Crops and buildings damaged.	Do.
Montana (southeastern counties)	21					Hail	Growing crops hurt.	Do.
Pocahontas County, Iowa	22	1:30-2 p.m.			25,000	Wind and hail	Crops damaged.	Do.
Newton, Ill., and vicinity	22	3:30 p. m.				do	Number of buildings damaged; poles and trees blown down, electric service interrupted; fruit and grain crops hurt.	Do.

Severe local storms, June, 1931—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Marshall County, Iowa	22	9 p. m.			$14,000	Wind	Buildings, fruit trees, and crops injured	Official, U. S. Weather Bureau.
Elgin (near), Ill	22					Wind and rain	Wheat and oats on several farms almost a total loss.	Do.
De Kalb County, Ill. (northern)	22					Wind, hail, and rain.	Oats, hay, fruit, and gardens almost total loss in places; roofs damaged; wire services interrupted.	Do.
Dubuque, Iowa	22					Wind	Factories and residence considerably damaged	Do.
Macoupin County, Ill. (central)	22					do	Several buildings damaged; trees and wheat blown down.	Do.
Montana (northeastern counties)	22					Hail	Growing crops damaged	Do.
Hopkins, S. C	23	9-10 p. m.			3,000	Hail and wind	Crops, cabins, and outbuildings damaged	Do.
Montana (south-central counties)	23					Hail	Growing crops damaged	Do.
Evansville, Ind., and vicinity	24				30,000	Electrical	Telephone lines, homes and other buildings damaged.	Do.
Franklin County, Miss	24			1		Thunder squall	Residences damaged	Do.
Statesboro (near), Ga	25					Wind	Several tobacco barns damaged; many trees blown down.	Do.
Michigan (straits to southern boundary).	26	4:30—9 a. m.		2		Wind, electrical and rain.	Many buildings damaged; trees uprooted	Do.
Sunbury, Pa., and vicinity	26				10,000	Electrical	Garages and autos wrecked; crops damaged	Do.
Ohio (northern)	26-27			4		Thunderstorms and wind.	Extensive destruction of property of all kinds; Cleveland hardest hit; 1 person injured.	Do.
Montana (east-central counties)	28					Hail	Crops damaged	Do.
Kettle Falls, Wash	29	2:30 p. m.			25,000	Thunder and hail	Chief damage to apple crop	Do.
Thomas to Sedan (near), N. Mex.	29	3-4:15 p.m.				Hail	Considerable damage, character not reported; path 15 miles long.	Do.
Rock Hill, S. C	29	P. m.			3,000	Hail and wind	Character of damage not reported	Do.
Montana (north-central and central counties.)	29				100,000	Hail	Severe crop damage	Do.
Indiana	29					11 severe wind storms.	Character of damage not reported	Do.
Bunker Hill, Ill	30	6 p. m.	3 mi.		10,000	Wind	Buildings damaged or wrecked; poles and trees blown down; crops flattened; path 5 miles.	Do.
Gordo (near), Ala	30					Wind and hail	Number of small buildings wrecked; trees uprooted.	Do.
Hernando, Miss., and vicinity	30				3,000	Violent wind and hail.	Character of damage not reported	Do.
Literbury, Ill., and vicinity	30					Wind and rain	Small buildings and crops damaged; 2 persons injured.	Do.

RIVERS AND FLOODS

By MONTROSE W. HAYES

Many of the rivers in the mid-western and far-western States were still at very low stages in June, and in no part of the country were there any river rises of importance. Heavy rains in northeastern Missouri and southern Kansas overflowed creeks, and caused damage estimated at $9,000 in Missouri and $4,000 in Kansas.

Table of bankful stages in June, 1931

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ATLANTIC SLOPE DRAINAGE	*Feet*			*Feet*	
Connecticut: Hartford, Conn	16	10	13	17.6	11
MISSISSIPPI SYSTEM					
Upper Mississippi Basin.					
Illinois: Peru, Ill	14	25	25	14.1	25
Arkansas Basin.					
Fountain: Fountain, Colo	8	25	25	8.6	25
GULF OF CALIFORNIA DRAINAGE					
Colorado: Parker, Ariz	7	1	30	8.0	10-15
PACIFIC SLOPE DRAINAGE					
Columbia Basin.					
Columbia: Marcus, Wash	24	12	16	24.2	13, 14

THE WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

F. A. YOUNG, Temporarily in Charge, Marine Division

NORTH ATLANTIC OCEAN

By F. A. YOUNG

With the exception of a tropical disturbance of slight intensity and a few local squalls, that will be described later, the North Atlantic during the current month was unusually free from heavy weather. Up to the time of writing only 15 vessels have rendered storm reports, and of these only 2 recorded a wind force as high as 10, while gales were not reported on more than one day in any 5° square.

There was an intrusion of low pressure over the region usually occupied by the North Atlantic high during the first 12 days of the month, while from the 13th to the 30th this center of action was well developed.

The number of days on which fog was reported in different sections of the ocean is as follows: Over the Grand Banks, from 10 to 15 days; along the American coast, north of the thirty-fifth parallel, from 12 to 19 days; over the northern steamer lanes, between the tenth and forty-fifth meridians, from 3 to 5 days; along the European coast, from 1 to 9 days.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, 8 a. m (seventy-fifth meridian), North Atlantic Ocean, June, 1931*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	[1] 30.07	([2])	30.48	3d	29.64	24th.
Belle Isle, Newfoundland	29.92	[3] +0.08	30.42	9th	29.14	23d.
Halifax, Nova Scotia	29.92	[4] −0.05	30.20	26th	29.60	21st.[5]
Nantucket	29.94	[4] −0.06	30.20	22d [5]	29.66	8th.
Hatteras	30.02	[4] 0.00	30.20	26th	29.60	8th.
Key West	29.99	[4] +0.01	30.10	3d	29.88	8th.[5]
New Orleans	30.03	[4] +0.03	30.14	3d	29.88	8th.
Cape Gracias, Nicaragua	29.84	[3] −0.05	29.94	2d	29.80	28th.[5]
Turks Island	30.04	[4] +0.01	30.12	18th	29.94	8th.[5]
Bermuda	30.05	[4] −0.08	30.26	23d	29.84	29th.
Horta, Azores	30.15	[3] −0.06	30.50	22d	29.62	2d.[5]
Lerwick, Shetland Islands	29.92	[3] +0.12	30.32	4th	29.35	15th.
Valencia, Ireland	29.98	[3] −0.02	30.39	29th	29.49	10th.
London	30.04	[3] +0.11	30.39	25th	29.54	13th.

[1] Average of 28 observations.
[2] No normal available.
[3] From normals shown on Hydrographic Office Pilot Charts, based on observations at Greenwich mean noon, or 7 a. m., seventy-fifth meridian time.
[4] From normals based on 8 a. m. observations.
[5] On other date or dates.

On the 1st there was a fairly well developed low of limited extent, central near 43° N., 25° W., that drifted slowly northeastward, decreasing in intensity. From that date until the 5th a few vessels in the eastern section of the steamer lanes reported winds of force 7 to 9, although moderate weather prevailed over the greater part of this region, as well as over the remainder of the ocean.

From the 6th to 8th moderate gales were again reported between the forty-fifth meridian and the Azores. On the 9th one of the most severe disturbances of the month was central about 300 miles north of the Bermudas; this moved but little during the next 24 hours, and on the 10th moderate westerly gales were encountered by a number of vessels between the fortieth and forty-fifth parallels.

From the 11th to 13th moderate weather, with comparatively high pressure, was the rule over the greater part of the ocean, and no storm reports were received for that period.

On the 14th and 15th an area of low pressure was over the steamer lanes, east of the thirtieth meridian, and moderate southwesterly gales occurred over a limited area.

From the 16th to 24th there ensued a period of unusually quiet weather over practically the entire ocean, with the exception of a moderate low on the 21st, central near 43° N., 52° W.

On the 25th a depression was over the peninsula of Yucatan, that afterwards developed into a moderate tropical disturbance. On the daily weather map for June 26 it is stated: "A disturbance of moderate intensity is apparently central in the south-central portion of the Gulf of Mexico." On the 27th the center of this disturbance was about 100 miles east-northeast of Brownsville, Tex., and on the 28th over the coast of western Texas. The Honduran steamship *Choluteca* was the only vessel rendering a report of this storm, as shown in table.

Charts VIII to X cover the period from the 23d to 25th, inclusive. Charts VIII and IX give an idea of the weather encountered by Messrs. Post and Gatty on the first two days of their around-the-world flight, and Chart X is drawn to show the conditions on the 25th, when Messrs. Hillig and Hoiriis landed in Germany.

Notes.—British steamship *Olna;* captain, P. Skone-Rees; observer, Sydney Mitchell, chief officer. Montreal to Port Arthur:

June 19, 1931, from 4 p. m. to 5:30 p. m. A. T. S.: A heavy electrical storm; clouds, Ci.-Cu., Cu. and Cu.-Nimb. Continual thunder and lightning. Occasional squalls traveling from NW. to SE., with an inclination to the southward and SW. This was preceded by a remarkable display of waterspouts, as many as five being seen at the same time and reforming as quickly as they dispersed. Position, between 24° 25′ N., 82° 08′ W., at beginning to 24° 25′ N., 82° 20′ W., at end.

Greek steamship *Okeania;* captain, Isadore M. Carivalis; observer, Master. Gibraltar to Baltimore:

Waterspout, June 4, in 36° 14′ N., 56° 37′ W., 6:30 p. m. ship time. Observed waterspout on starboard bow (ship course west) 3 miles distant. Lasted until 7:30 p. m. Barometer 29.81 (corrected); clouds Cu.-Nb. from SW., 7 to 10. Air temperature, 66; water, 72.

American steamship *San Julian;* captain, G. V. Spankie; observer, M. Sander, chief mate. From Philadelphia to Canal Zone:

June 29, 3:30 a. m. E. S. T., in 16° 00′ N., 75° 40′; wind NW., 4. Vessel entered very heavy electrical disturbance. Lightning, thunder, and torrential rain; wind calm and variable. At 7 a. m. in 15° 30′ N., 75° 50′ W., wind SE., 3, then to NE., 3, and calm in afternoon. About one hour before entering this, wind had been NE., 4, then shifted to NW. When near the center the thunder and lightning were almost continuous.

OCEAN GALES AND STORMS, JUNE, 1931

Vessel	Voyage From—	Voyage To—	Position at time of lowest barometer: Latitude	Position at time of lowest barometer: Longitude	Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
			° ′	° ′				Inches					
NORTH ATLANTIC OCEAN													
Aracataca, Br. S. S.	Rotterdam	Tela, Honduras.	39 16 N	32 20 W	June 1	Noon 2	June 3	29.63	SSW	SSW, 9	NW	SSW, 9	SSW-NW.
Ogontz, Am. S. S.	Pasajes, Spain.	New Orleans.	35 20 N	38 40 W	June 6	Mdt. 6	June 7	29.75	SW	W, 6	W	W, 8	SW-W-WNW.
Cripple Creek, Am. S. S.	New Orleans.	Liverpool	38 47 N	64 42 W	June 9	2 p. 9	June 9	29.48	E	E, 10	S	E, 10	E-SE-S.
Marie Leonhardt, Ger. S. S.	New York	London	40 33 N	60 23 W	do	— 9	do	29.88	E	E, 9	E	E, 9	Steady.
Berlin, Ger. S. S.	Bremerhaven	New York	48 43 N	22 15 W	June 14	Mdt. 14.	June 15	29.31	SSW	SSW, 10	NW	SSW, 10	SSW-W.
Nieuw Amsterdam, Du. S. S.	Rotterdam	do	50 43 N	15 03 W	June 15	8 a. 15	do	29.47	SSW	SSW, 8	WSW	SSW, 8	SSW-WSW.
Tulsa, Am. S. S.	Savannah	Liverpool	39 49 N	53 38 W	June 21	2 a. 21	June 21	29.72	SSW	SSW, 8	SSW	SSW, 8	Steady.
Choluteca, Hond. S. S.	Baltimore	Tela, Honduras.	20 32 N	85 38 W	June 25	7 a. 25	June 25	29.59	E	SE, 6	SE	SE, 8	
Okeania, Gr. S. S.	do	Lisbon	39 54 N	51 12 W	June 24	Noon 25.	do	30.02	SSW	SW, 6	NW	SW, 8	S-SW.
San Tirso, Br. S. S.	Minatitlan	Manchester	40 25 N	55 14 W	June 27	3 p. 28	June 28	29.71	WSW	S, 6	S	SSE, 8	
NORTH PACIFIC OCEAN													
Emma Alexander, Am. S. S.	San Francisco	Seattle	41 14 N	124 33 W	June 3	2 p. 3	June 3	29.98	NW	—, 8	NW	NW, 9	WNW-NW.
Iowa, Am. S. S.	Japan	San Francisco	41 48 N	157 37 E	June 4	8 p. 4	June 5	29.36	ENE	NE, 7	NW	WNW, 8	NE-N-NW.
Paris Maru, Jap. S. S.	Seattle	Yokohama	52 53 N	149 02 W	do	Mdt. 4	do	29.18	S	S, 8	SSW	S, 9	3 pts.
Granville, Pan. M. S.	Shanghai	San Pedro	45 54 N	163 30 W	June 10	8 p. 10	June 14	[1]29.54	E	E, 8	WNW	WNW, 9	
City of Elwood, Am. M. S.	do	Honolulu	31 30 N	154 08 E	June 11	5 a. 12	June 12	29.20	SE	S, —	SW	S, 8	SE-S.
Tejon, Am. S. S.	Yokohama	San Pedro	42 00 N	139 00 W	do	— 13	June 13	29.37	SE	NE, 8	W	—, 9	
Golden Tide, Am. S. S.	Hong Kong	San Francisco	34 24 N	140 16 E	June 12		June 12	29.60	ESE		S	ESE, 9	ESE-S.
Olympia, Am. S. S.	Orient	do	43 16 N	169 50 W	do	— 13	June 14	[1]29.44	E	S, 8	SW	S, 8	SE-S-SW.
City of Victoria, Can. S. S.	Japan	do	39 48 N	168 32 W	June 16	Noon 16.	June 17	29.74	SE	SE, 7	SSW	—, 8	
Seattle, Am. S. S.	Celebes	do	39 15 N	157 55 W	June 22	5 a. 23	June 23	29.79	S	SW, 6	SW	SW, 8	S-SW-W.
Iowan, Am. S. S.	Los Angeles	Balboa	16 59 N	103 16 W	June 23	6 a. 23	do	29.75	SE	SE, 6	SSE	E, 8	SE-E
Blythmoor, Br. S. S.	Vancouver	Panama	19 48 N	106 29 W	June 24	10 p. 24	June 24	29.74	NW	E, 8	SE	E, 8	N-E-SE.

[1] Barometer uncorrected.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

Atmospheric pressure.—During June, 1931, the Aleutian LOW was slightly deeper than normal for the month, especially to the westward of the peninsula of Alaska, where also the pressure was lower than in the previous month, thus showing an early summer intensification. On the average a distinct center of 29.81 inches barometer extended from the Gulf of Alaska westward to beyond Dutch Harbor. During strongest developments of the LOW the barometer fell to a minimum of 29.10 inches at Kodiak on the 5th, and to 29.02 at Dutch Harbor on the 15th.

The North Pacific HIGH covered an extensive area in middle latitudes over the eastern half of the ocean throughout the month, its eastern extremity lying along the coast of the United States except on five or six days, when the northern LOW intervened by extending unusually far southward. Over the western part of the ocean in these latitudes pressure was fluctuating and unstable.

The following table gives barometric data for several island and coast stations in west longitudes, including Point Barrow on the Arctic Ocean:

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, at indicated hours, North Pacific Ocean and adjacent waters, June, 1931*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	Inch	Inches		Inches	
Point Barrow [1] [2]	29.99	0.00	30.20	8th [3]	29.74	11th.
Dutch Harbor [1]	29.81	−0.09	30.26	13th	29.02	15th.
St. Paul [1]	29.88	+0.02	30.30	13th	29.12	15th.
Kodiak [1]	29.81	−0.10	30.16	1st [3]	29.10	5th.
Midway Island [1]	30.04	−0.01	30.16	19th [3]	29.74	3d.
Honolulu [4]	30.06	+0.02	30.15	17th	29.93	6th.
Juneau [4]	29.93	−0.08	30.32	3d	29.48	21st.
Tatoosh Island [4] [5]	29.99	−0.06	30.25	4th	29.73	25th.
San Francisco [4] [5]	29.96	0.00	30.11	16th	29.81	4th.
San Diego [4] [5]	29.92	+0.03	30.03	15th	29.74	22d.

[1] P. m. observations only used in averages; a. m. and p. m. in extremes.
[2] For 29 days.
[3] And on other date or dates.
[4] A. m. and p. m. observations.
[5] Corrected to 24-hour mean.

Depressions and gales.—June witnessed comparatively quiet weather over the entire North Pacific, with an absence of tropical storms, as well as of gales exceeding 9 in force, so far as now indicated by reports.

In east longitudes, particularly toward the Asiatic coast, numerous tropical and extratropical depressions gathered, those in lower waters dissipating or moving out of the field without much show of energy. In the Japanese area only one cyclone of the month is indicated as displaying marked strength. This skirted the lower coast of Japan and caused gales of force 8 to 9 on the 12th from Kiushu Island to southeastern Honshu.

A depression lying north of Midway Island on June 1 moved into the Aleutian region on the 2d, and thence into the Gulf of Alaska on the 4th and 5th, where isolated southerly gales of force 9 were reported near 53° N., 148° W., during the time of greatest intensification of cyclonic energy over the northeastern part of the ocean for the month.

From the 11th to 14th a series of gales of force 8 to 9 was encountered along the northern routes between about latitudes 40° and 50° N., longitudes 135° and 170° W. These were caused by two depressions, the more easterly of which lay south of the Gulf of Alaska for two or three days, becoming more and more restricted in area until, as a small LOW, it entered the Washington-Oregon coast on the 15th. The other depression entered the Aleutian area from the southwest on the 13th, causing fresh gales along its eastern boundary on that date. By the 15th, then central in the southern part of the Bering Sea, it acquired considerable depth, giving the lowest pressure of the month over the central Aleutians, and a reported gale of force 9 from the west nearly south of Atka Island.

On the 3d and 4th of the month there was a strong northwesterly air current off the American coast between Tatoosh Island and Eureka, blowing along the eastern edge of the HIGH and rising in force at times to that of a fresh to strong gale.

In the Mexican coast region, during the prevalence of slight depressions over lower and upper Mexico, a fresh

easterly gale was experienced on the 23d off Acapulco, a moderate gale in the Gulf of Tehuantepec on the 24th, and a fresh easterly gale on the same date off central Lower California. Aside from these, no gales were reported from the entire ocean south of the thirtieth parallel.

Winds at Honolulu.—While there were some southerly winds at Honolulu early in June, due to the depression then west and northwest of the Hawaiian Islands, the prevailing direction for the month was east, with the maximum velocity, 24 miles from the east, on the 22d.

Fog.—In the average year fog increases greatly in frequency and extent over the upper waters of the North Pacific, especially along the western part of the routes, during June. This year the June percentage of fog was slightly less than in the previous May over the region of the summer fog bank lying east and southeast of the Kuril Islands, except in the 5° square, 43° to 48° N., 155° to 160° E., where it occurred on 10 days, or with about its frequency in the previous month. Along the middle part of the upper routes the occurrence was light, but south of the Gulf of Alaska, from longitude 150° W. to the coast, it was encountered on three to five days in each 5° square. The heaviest coastal occurrence was between Eureka and San Diego, where it was reported on nine days. Farther southward it was met with occasionally to Cape San Lucas. In mid-ocean, between 30° and 35° N., 165° E. to 165° W., fog was unusually frequent, forming here and there along the strip from the 17th to the 27th.

Volcanic phenomena.—The British steamer *Narenta* was in port of San Jose de Guatemala during the day of June 5. Mr. C. K. Brown, third officer of the vessel, on this day reported: "Volcano Isalco in eruption. Lava flowing freely down side like a waterfall. Visible at 50 miles through rain."

Mr. F. E. Holmes, observer on the American steamer *Victoria*, reported in June (date not given, but between the 8th and the 26th): "While laying at the dock at False Pass, Alaska, latitude 54° 51′ N., longitude 163° 22′ W., noted some fine brown sand or lava falling, evidently from Volcano Shishaldin."

BUCKET OBSERVATIONS OF SEA-SURFACE TEMPERATURES

By GILES SLOCUM

STRAITS OF FLORIDA AND CARIBBEAN SEA

The temperatures herein published are the means of the average temperatures for the four quarters of the month, except that, in the case of the 5° subdivisions of the Caribbean Sea, the figures shown are the simple means of the observed temperatures with the entire month taken as a unit. Table 1 shows the lengths of the quarters for each length of month.

Table 2 shows the average temperature for the Caribbean Sea and the Straits of Florida for June of each year from 1919 to 1930, inclusive, and Table 3 summarizes the temperature for the month in the same areas, including the departures of the June, 1930, means from the 11-year means for June, 1920–1930, and the changes from the temperatures for the preceding month of May, 1930.

The chart shows the number of observations taken during the month of June, 1930, within each 1° square; the mean temperature of the Straits of Florida, and of each 5° [1] subdivision of the Caribbean Sea; the 11-year means (1920–1930) for these areas; and the local mean time corresponding to Greenwich mean noon, at which time the mariners are instructed to make the temperature readings.

June marks the end of what may be called the cool season in the Caribbean Sea. From the 1st to about the middle of the month, under average conditions, the seasonal march of sea-surface temperatures continues to exhibit nearly as strong an upward trend as that found in May, but this rapid rise does not continue through the rest of the month. Instead, it becomes more gradual than is found in the first half of June, in the spring weeks, or in the late summer. The Straits of Florida region, hitherto cooler than the Caribbean Sea, becomes the warmer of the two areas, with the time of the reversal in relative temperature varying from early June to near the beginning of July.

In average years within the Straits of Florida, June is the month of most rapid rise in temperature during the entire year, with the 11 years' record showing no June as cool as the warmest May.

Comparing the two areas by quarter months, the Caribbean has usually been warmer than the Straits during the first quarter of June; as often the cooler as the warmer during the second quarter, although its temperature averages slightly higher for the 11 years; cooler than the Straits during the third quarter, with exceptions in 1926 and 1930; and at no time warmer during the fourth quarter, unless the doubtful case of 1919, when observations were few, be included. In the Straits of Florida the third and fourth quarters of June have thus been almost uniformly periods when the surface water was distinctly warmer there than in the Caribbean Sea, with the result that the Straits show a higher mean temperature for the month.

In June, 1930, the Caribbean Sea was somewhat cooler than average east of the seventieth meridian, close to the average in the Cuba-Jamaica region and north of the eastern Colombia coast, and warmer than the 11 year mean over the rest of the sea, with the plus departures large in Central American waters. The fourth quarter of June was cooler than the third over the region east of the seventy-fifth meridian, and in that area west of this longitude and south of the fifteenth parallel. For the fourth successive month the mean temperature of the sea as a whole was somewhat above the seasonal average.

In the Straits of Florida, June was notably an abnormal month. The observational readings for the first and fourth quarters gave computed mean temperatures well below the usual values, while those for the second and third quarters and for the month as a whole averaged the lowest for these periods since records began.

This coolest June in the Straits area followed a month with sea-surface temperatures, within the range of statistical possible error arising from limited size of samples, as high as in any preceding May, the difference between these two months in 1930 being only 0.8°. The smallness of this May-to-June range in temperature constitutes another record without precedent or near approach. The anomaly of this near approach to equality between the two monthly temperatures becomes increasingly manifest when the 0.8° difference is contrasted with the mean range of 2.9° between May and June for the 10-year period of 1920 to 1929.

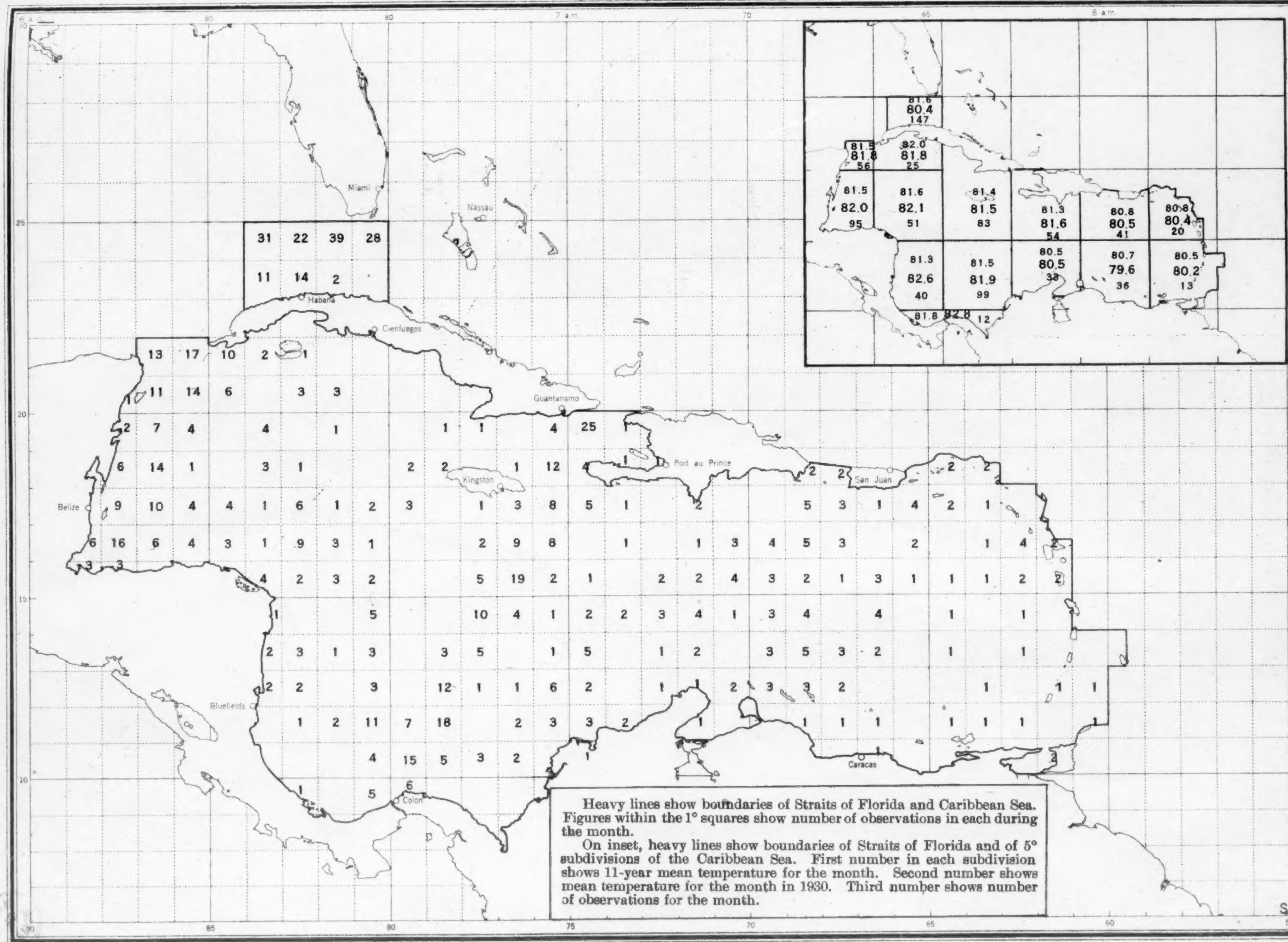
No theory is offered in explanation for, or in support of, a cause-and-effect relation between the cool water in June in the Straits of Florida and the 1930 drought. The period covered by sea-surface temperature records in workable volume includes only a few recent years, and

[1] In 3 cases, as indicated on the chart, the observations from small, little traveled, and unimportant areas at the outer limits of the Caribbean Sea have been treated as parts of contiguous 5° subdivisions.

Distribution of Greenwich Mean Noon Bucket Observations of Sea-Surface Temperatures, June, 1930
(Plotted by Giles Slocum)

Distribution of Greenwich Mean Noon Bucket Observations of Sea-Surface Temperatures, June, 1930

(Plotted by Giles Slocum)



Heavy lines show boundaries of Straits of Florida and Caribbean Sea. Figures within the 1° squares show number of observations in each during the month.

On inset, heavy lines show boundaries of Straits of Florida and of 5° subdivisions of the Caribbean Sea. First number in each subdivision shows 11-year mean temperature for the month. Second number shows mean temperature for the month in 1930. Third number shows number of observations for the month.

conclusions would be difficult to draw if not quite impossible to verify to any accurate degree. The coincidence, however, of extreme conditions—low temperature in the Straits of Florida surface waters and scanty precipitation in the regions receiving ultimately nearly all their rainfall from the Gulf of Mexico and western North Atlantic sources—is interesting in its implications.

Dr. C. F. Brook's analysis of thermograms from the condenser-intake of the *Henry M. Flagler*,[2] paralleling in every respect, as it does, the results from the Weather Bureau records in regard to temperature marches, and agreeing with them in absolute values to well within the limits of differences to be expected in data not completely comparable, lends support to the reality and amplitude of the computed temperature anomaly.

TABLE 1.—*Lengths of "quarter months" used in computing mean sea-surface temperatures*

Length of month	Days of month included in quarter			
	I	II	III	IV
28 days	1-7	8-14	15-21	22-28
29 days	1-7	8-14	15-21	22-29
30 days	1-7	8-15	16-22	23-30
31 days	1-7	8-15	16-23	24-31

[2] This ship, a car ferry plying between Key West and Habana, installed thermographic equipment in 1928, from the records of which equipment Doctor Brooks made his study. Due to lay-overs in dock by the ship, the records were somewhat fragmentary. The study was brought to a close with the June 3-9 record in 1930. The periods available for comparisons in the present writing were: May 27-June 2, 1929; June 17-23, 1929; May 27-June 2, 1930; and June 3-9, 1930. Cf. Charles F. Brooks. Gulf Stream daily thermograms across the Straits of Florida. MONTHLY WEATHER REVIEW, April, 1930, 58: 148-154; and Charles F. Brooks and Edith M. Fitton. Weekly succession of Gulf Stream Temperatures in the Straits of Florida. Ibid July, 1930, 58: 273-280.

TABLE 2.—*Mean sea-surface temperatures in the Caribbean Sea and the Straits of Florida for June, 1919–1930*

Year	Caribbean Sea		Straits of Florida	
	Number of observations	Mean temperature	Number of observations	Mean temperature
		°F.		°F.
1919 [1]	65	82.2	32	81.1
1920	208	81.1	25	81.0
1921	169	81.1	54	81.3
1922	181	80.5	98	81.8
1923	348	80.4	97	81.1
1924	347	82.0	109	82.8
1925	570	81.2	141	81.5
1926	468	82.1	138	81.6
1927	399	81.8	143	82.4
1928	691	81.6	167	81.8
1929	839	81.2	186	81.4
1930	658	81.5	147	80.4
Mean (1920-1930)		81.3		81.6

[1] Not used in computations because of insufficient data available.

TABLE 3.—*Mean sea-surface temperatures (°F.) and number of observations, June, 1930*

Quarter	Period	Caribbean Sea				Straits of Florida			
		Number of observations	Mean	Departure from 11-year mean (1920-1930)	Change from preceding month	Number of observations	Mean	Departure from 11-year mean (1920-1930)	Change from preceding month
			°F.	°F.	°F.		°F.	°F.	°F.
I	June 1-7	144	81.2			38	80.2		
II	June 8-15	183	81.5			34	79.6		
III	June 16-22	148	81.7			36	80.2		
IV	June 23-30	183	81.7			39	81.8		
Month		658	81.5	+0.2	+0.5	147	80.4	-1.2	+0.8

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, June, 1931

[For description of tables and charts, see February, 1931, REVIEW, p. 50]

Section	Temperature								Precipitation					
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
	° F.	° F.		° F.			° F.		In.	In.		In.		In.
Alabama	79.9	+1.7	Talladega	109	28	St. Bernard	44	2	1.49	−2.91	Silverhill	4.67	Centerville	0.17
Arizona	76.3	−0.4	Gila Bend	119	30	Alpine	25	5	0.70	+0.32	Canille	3.58	8 stations	0.00
Arkansas	78.3	+1.4	Amity	107	30	Dutton	35	1	2.60	−1.50	Hot Springs	6.03	Big Lake Outlet	0.36
California	66.6	−0.9	Greenland Ranch	116	24	Ellery Lake	25	16	0.77	+0.46	Kennett	3.88	12 stations	0.00
Colorado	64.9	+3.5	Las Animas	110	23	Pearl	23	[1] 4	1.25	−0.26	Arriba	4.03	Sunbeam	0.05
Florida	80.0	+0.2	Monticello	109	29	Vernon	48	9	2.12	−4.49	Everglades	5.25	2 stations	0.00
Georgia	80.4	+2.5	2 stations	109	[1] 28	Tallapoosa	41	9	1.80	−2.68	Clayton	5.15	Fitzgerald	0.01
Idaho	63.3	+2.8	Orofino	103	7	Atlanta	23	24	0.63	−0.60	Bismarck Ranger Station.	2.82	3 stations	0.00
Illinois	75.3	+3.7	2 stations	107	[1] 29	Danville	37	1	3.17	−0.76	Quincy	7.88	Carbondale	0.34
Indiana	73.9	+2.7	Edwardsport	109	28	Delphi	34	1	3.61	−0.25	Royal Center	8.97	Mauzy	1.31
Iowa	75.0	+5.7	2 stations	106	28	Estherville	36	8	3.73	−0.77	Waukee	8.11	Cedar Falls	1.31
Kansas	77.8	+4.8	do	106	[1] 20	Tribune	44	7	2.15	−1.91	Eldorado	7.72	Johnson	T.
Kentucky	75.3	+1.5	Henderson	106	29	Mount Sterling	39	2	2.79	−1.46	Oneonta	5.49	2 stations	1.31
Louisiana	79.7	−0.4	Lake Providence	105	29	2 stations	48	2	2.02	−2.79	Hammond	5.20	Logansport	0.00
Maryland-Delaware	70.8	0.0	Cumberland, Md	102	20	Sines, Md	35	10	3.43	−0.50	Westminster, Md	5.93	Cumberland, Md	1.37
Michigan	66.7	+3.1	Seney	103	30	Wolverine	20	1	3.40	+0.28	Albion	7.67	Gladwin	0.91
Minnesota	69.5	+5.5	Canby	110	29	Big Falls	28	1	3.95	−0.08	Tower	8.71	Roseau	1.25
Mississippi	79.7	+1.0	Columbus	108	30	4 stations	48	[1] 2	2.32	−1.89	Columbia	7.95	Rosedale	0.19
Missouri	77.1	+3.9	Marble Hill	107	29	2 stations	40	[1] 1	2.94	−1.93	Philadelphia	9.14	Osceola	0.56
Montana	64.2	+4.4	Frazer	110	16	Loweth	20	24	1.34	−1.20	Glendive	3.25	Augusta	0.38
Nebraska	75.7	+6.7	Santee	109	28	Mullen	35	[1] 5	2.43	−1.35	Weeping Water	6.14	Lyman	0.20
Nevada	67.0	+1.5	Clay City	112	11	Zorra Vista Ranch	27	28	0.48	−0.01	Lewers Ranch	1.69	2 stations	0.04
New England	64.3	+0.5	Turners Falls, Mass.	100	30	Pittsburg (a), N. H.	32	22	5.45	+2.07	Swampscott, Mass.	10.81	St. Albans, Vt	2.27
New Jersey	69.3	+1.0	Newton	101	20	Runyon	40	3	4.84	+0.96	Boonton	7.42	Bridgeton	2.18
New Mexico	69.6	+1.2	Cambray	108	20	Luna Ranger Station.	25	5	0.76	−0.56	Quemado	3.20	3 stations	0.00
New York	65.3	+0.6	Dansville	100	30	Indian Lake	29	2	3.45	−0.25	Boyds Corners	11.33	Syracuse	1.15
North Carolina	74.0	+0.2	Fayetteville	105	29	Mount Mitchell	30	9	2.55	−2.24	Kenansville	6.62	Chapel Hill	0.54
North Dakota	68.4	+5.9	2 stations	110	[1] 16	Hansboro	27	7	2.35	−1.10	McLeod	9.27	Powers Lake	0.11
Ohio	70.8	+1.7	4 stations	101	[1] 20	2 stations	35	2	3.58	−0.25	Kings Mills	6.99	Gallipolis	1.33
Oklahoma	79.7	+2.5	Goodwell	106	20	Smithville	41	1	2.01	−1.97	Cleveland	6.82	Walters	0.18
Oregon	60.0	+0.6	Umatilla	107	7	Seneca	16	30	2.31	+0.97	Astoria	7.70	Vale	0.23
Pennsylvania	68.5	+0.6	3 stations	102	[1] 20	Ridgway	28	2	3.71	−0.47	Natrona	8.08	Greenville	1.23
South Carolina	77.8	+0.4	Laurens	106	29	Walhalla	43	9	2.21	−2.57	Beaufort (near)	6.09	Aiken	0.11
South Dakota	74.4	+8.6	LaDelle	115	28	2 stations	35	[1] 5	2.37	−1.12	Ipswich	9.62	Vale	0.18
Tennessee	76.8	+2.3	2 stations	106	29	Crossville	34	9	1.86	−2.46	Covington	5.30	Parksville	0.08
Texas	80.6	+0.4	Fort Stockton	109	19	Alpine	46	2	2.01	−1.19	Runge	12.58	2 stations	0.00
Utah	68.1	+3.3	2 stations	104	[1] 24	Panguitch	29	2	0.25	−0.35	Monticello	1.34	3 stations	0.00
Virginia	72.3	+0.8	Lincoln	103	30	Burkes Garden	34	2	3.23	−1.06	Chatham	6.36	Quantico	0.70
Washington	60.3	−0.3	Wahluke	107	7	Paradise Inn	26	2	3.66	+2.16	Big Four	16.39	Hanford	0.51
West Virginia	69.8	+1.0	Charleston	105	20	Bayard	33	2	3.24	−1.38	Horton	7.18	Piedmont	1.12
Wisconsin	69.1	+4.6	Plum Island	106	30	Coddington	24	8	4.55	+0.51	Park Falls	10.84	Sturgeon Bay	1.56
Wyoming	63.0	+4.8	2 stations	105	28	Bedford	22	18	1.04	−0.54	Sundance	3.80	Thermopolis	0.00
Alaska [May]	30.8	−3.0	Tree Point	78	21	Eagle	2	[1] 3	2.08	+0.74	Yakutat	17.11	Barrow	T.
Hawaii	74.5	+1.3	Kaanapali	94	[1] 8	Kanalohuluhulu	45	[1] 9	2.84	−1.93	Puu Kukui (upper)	19.00	8 stations	0.00
Porto Rico	79.5	+1.1	Mayaguez	96	10	Guineo Reservoir	49	28	10.51	+4.27	San Lorenzo	25.11	Barceloneta	2.64

[1] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, June, 1931*

District and station	Elevation of instruments			Pressure			Temperature of the air										Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation			Wind					Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range				Total	Departure from normal	Days with 0.01 or more	Total movement	Prevailing direction	Maximum velocity: Miles per hour	Maximum velocity: Direction	Maximum velocity: Date						
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							**64.4**	**+0.8**										**77**	**5.10**	**+2.1**										**5.4**		
Eastport	76	67	85	29.85	29.93	0.00	57.0	+1.9	86	20	65	45	7	49	32	53	51	83	3.56	+0.6	15	6,717	nw.	40	e.	10	2	11	17	7.5	0.0	0.0
Greenville, Me	1,070	6	----	28.81	29.96	----	60.4	----	86	19	70	40	3	51	36	55	----	77	4.75	----	14	3,868	nw.	23	----	21	10	7	13	----	0.0	0.0
Portland, Me	103	82	117	29.82	29.94	-.01	64.2	+1.7	94	20	72	50	10	56	31	57	52	68	5.40	+2.1	14	5,475	n.	27	ne.	9	13	9	8	4.7	0.0	0.0
Concord	289	70	79	29.63	29.94	-.02	65.6	+2.7	94	20	77	44	25	55	35	----	----	----	5.35	+2.2	14	3,290	n.	20	nw.	26	15	6	9	4.6	0.0	0.0
Burlington	403	11	48	29.53	29.96	.00	63.4	-2.3	92	20	74	43	24	53	34	----	----	----	2.46	-0.9	13	4,577	n.	24	s.	8	9	10	11	5.5	0.0	0.0
Northfield	876	12	60	29.04	29.98	+.02	60.6	-0.7	90	30	73	38	24	48	40	59	57	84	4.00	+0.8	11	3,741	s.	19	n.	27	9	13	8	5.3	0.0	0.0
Boston	125	106	165	29.81	29.94	-.02	67.2	+0.7	97	20	75	48	10	59	26	60	55	68	9.13	+6.2	12	4,896	nw.	24	n.	5	9	12	9	5.6	0.0	0.0
Nantucket	12	14	90	29.91	29.92	-.06	62.0	+1.0	83	21	68	51	7	56	21	58	56	84	6.55	+3.9	10	9,386	n.	36	ne.	10	11	9	10	5.4	0.0	0.0
Block Island	26	11	46	29.90	29.93	-.04	63.5	+1.7	83	30	69	53	10	58	22	59	58	87	4.57	+2.0	8	8,872	sw.	36	ne.	10	12	7	11	5.3	0.0	0.0
Providence	160	215	251	29.77	29.93	-.04	67.3	-1.0	93	20	76	51	10	58	29	61	57	73	4.95	+2.3	12	6,862	nw.	28	nw.	21	16	3	11	4.8	0.0	0.0
Hartford	159	122	----	29.77	29.94	-.03	68.4	+1.3	94	20	78	52	10	59	33	----	----	----	4.75	+1.7	12	----	s.	----	----	----	13	8	9	5.1	0.0	0.0
New Haven	106	74	153	29.83	29.94	-.03	68.7	+2.1	96	20	77	53	10	60	31	62	58	73	5.33	+2.2	11	5,742	n.	24	nw.	21	10	10	10	5.5	0.0	0.0
Middle Atlantic States							**70.9**	**+0.6**										**70**	**3.20**	**-0.4**										**4.9**		
Albany	97	107	115	29.85	29.95	-.02	68.6	+0.6	95	20	78	52	4	59	31	61	56	68	4.00	+0.6	12	4,502	s.	22	n.	1	17	4	9	4.1	0.0	0.0
Binghamton	871	10	84	29.08	30.00	+.03	66.4	+0.8	94	30	78	44	2	55	36	----	----	----	1.75	-1.6	8	3,184	nw.	18	n.	17	7	11	12	6.1	0.0	0.0
New York	314	414	454	29.62	29.94	-.04	69.4	+0.6	93	20	77	54	9	62	24	61	56	68	4.00	+0.7	11	8,801	n.	42	nw.	7	9	10	11	5.9	0.0	0.0
Bellefonte	1,050	5	36	28.89	29.98	----	66.0	----	94	20	79	38	2	53	42	60	57	73	1.78	----	7	----	sw.	----	----	----	8	10	12	5.9	0.0	0.0
Harrisburg	374	94	104	29.60	29.99	.00	71.0	+0.7	98	20	81	52	2	61	32	62	56	62	3.28	-0.3	8	3,865	ne.	29	w.	7	11	11	8	4.8	0.0	0.0
Philadelphia	114	123	367	29.86	29.98	.00	72.9	+1.5	98	20	81	57	9	64	28	63	57	62	3.75	+0.5	10	8,099	n.	34	s.	7	9	13	8	5.2	0.0	0.0
Reading	325	81	98	29.63	29.77	----	71.0	+1.2	98	20	81	51	2	61	29	62	56	61	4.86	+1.3	9	3,496	n.	16	n.	9	11	11	8	5.0	0.0	0.0
Scranton	805	111	119	29.14	29.99	+.01	68.0	+0.2	95	20	79	47	3	57	36	61	56	69	3.04	-0.6	9	4,022	n.	33	nw.	20	11	11	8	5.1	0.0	0.0
Atlantic City	52	37	172	29.91	29.96	-.02	68.4	+1.8	94	30	75	56	9	62	25	63	60	79	2.54	-0.5	8	9,153	s.	34	s.	7	12	11	7	4.8	0.0	0.0
Cape May	17	13	49	----	----	----	68.5	+0.8	89	30	76	56	2	61	23	64	61	80	2.50	-0.5	8	----	se.	----	----	----	4	17	9	----	0.0	0.0
Sandy Hook	22	10	55	29.92	29.94	----	68.8	----	90	20	76	54	10	62	24	63	60	78	3.66	-0.1	9	7,518	sw.	35	nw.	7	15	9	6	4.1	0.0	0.0
Trenton	190	159	183	29.76	29.96	----	70.4	+0.9	95	20	80	54	3	61	31	63	59	72	4.28	+1.2	14	5,724	n.	41	nw.	7	8	13	9	5.5	0.0	0.0
Baltimore	123	100	215	29.8[illegible]	29.97	-.02	74.5	+1.8	100	20	83	56	2	66	27	64	59	62	1.89	-2.0	9	6,436	sw.	30	sw.	7	12	11	7	5.1	0.0	0.0
Washington	112	62	85	29.86	29.98	-.02	73.3	+1.1	99	20	83	52	3	64	31	64	59	66	2.12	-2.0	10	3,473	nw.	27	n.	26	12	12	6	4.3	0.0	0.0
Cape Henry	18	8	54	29.96	29.98	----	72.0	-0.9	93	20	79	56	3	65	27	66	64	77	3.43	-0.5	9	6,672	sw.	31	n.	1	12	12	6	4.5	0.0	0.0
Lynchburg	681	153	188	29.26	29.99	-.02	74.5	-0.1	98	20	86	52	2	64	32	66	63	70	2.43	-1.4	7	3,503	n.	33	nw.	22	14	12	4	4.1	0.0	0.0
Norfolk	91	170	205	29.90	30.00	.00	73.8	-0.6	92	21	83	58	2	65	26	65	62	72	5.13	+0.9	8	6,812	s.	43	w.	23	13	10	7	4.5	0.0	0.0
Richmond	144	11	52	29.84	29.99	-.02	73.8	-0.3	95	21	84	51	2	63	30	66	63	72	2.98	-0.9	8	4,138	sw.	28	sw.	7	13	11	6	4.1	0.0	0.0
Wytheville	2,304	49	55	27.69	30.00	-.01	68.6	-0.1	92	20	81	41	2	56	37	61	57	71	2.05	-2.2	7	2,826	w.	24	ne	21	10	13	7	5.0	0.0	0.0
South Atlantic States							**77.3**	**+0.9**										**69**	**2.20**	**-2.4**										**4.2**		
Asheville	2,253	89	104	27.74	30.02	+.01	71.8	+3.1	95	28	84	45	2	59	35	63	59	71	3.44	-0.5	9	3,375	nw.	23	n.	15	13	15	2	3.6	0.0	0.0
Charlotte	779	55	62	29.19	30.01	.00	77.8	+2.3	98	23	89	53	9	66	30	67	61	61	0.60	-3.6	6	2,425	s.	15	w.	7	11	13	6	4.5	0.0	0.0
Greensboro	886	6	56	29.08	30.02	----	74.0	----	98	21	87	46	9	61	34	66	62	70	2.27	----	9	4,424	sw.	41	nw.	21	8	16	6	5.2	0.0	0.0
Hatteras	11	5	50	29.99	30.00	-.01	72.7	-2.9	86	24	80	57	3	66	22	68	66	81	3.82	-0.7	4	7,386	sw.	44	w.	8	19	8	3	3.0	0.0	0.0
Raleigh	376	103	146	29.61	29.99	-.02	76.4	+0.7	96	27	87	53	2	66	28	67	62	64	2.53	-1.9	5	4,691	sw.	33	nw.	5	6	21	3	4.9	0.0	0.0
Wilmington	78	81	91	29.95	30.03	+.02	75.8	-1.0	93	24	84	56	9	67	25	69	65	74	1.82	-3.3	8	4,222	sw.	19	s.	7	19	8	3	3.5	0.0	0.0
Charleston	48	11	92	29.97	30.02	+.01	78.4	-0.5	97	28	85	63	9	72	21	71	68	75	2.46	-2.1	7	6,452	sw.	35	sw.	7	11	14	5	4.3	0.0	0.0
Columbia, S. C	351	41	57	29.64	30.01	.00	79.2	+1.1	101	28	91	55	9	68	31	67	62	61	1.85	-2.3	5	3,799	s.	28	sw.	7	17	10	3	3.9	0.0	0.0
Due West	711	10	55	29.28	30.04	----	78.8	----	103	29	91	54	9	66	32	----	----	----	2.39	----	9	4,547	s.	32	n.	29	12	11	7	4.8	0.0	0.0
Greenville, S. C	1,039	139	146	28.93	30.00	----	78.6	+4.5	101	29	89	56	9	68	27	66	60	60	0.78	-3.8	5	4,135	ne.	32	sw.	7	12	14	4	4.3	0.0	0.0
Augusta	182	62	77	29.80	29.99	-.02	80.9	+2.2	105	28	93	57	9	69	30	70	65	65	1.29	-3.4	10	3,352	s.	30	n.	6	12	14	4	4.0	0.0	0.0
Savannah	65	150	194	29.94	30.01	.00	79.6	+0.6	98	29	90	60	9	70	30	71	68	74	2.68	-2.6	8	6,589	s.	42	n.	24	18	5	7	3.9	0.0	0.0
Jacksonville	43	209	245	29.97	30.02	+.01	79.6	-0.3	98	29	88	61	9	71	26	71	67	72	2.97	-2.4	7	6,449	s.	32	sw.	6	12	15	3	4.4	0.0	0.0
Florida Peninsula							**81.2**	**+0.5**										**74**	**1.17**	**-5.0**										**5.1**		
Key West	22	10	64	29.97	29.99	.00	81.7	-0.2	91	16	87	71	22	76	14	75	73	75	1.96	-2.3	7	5,783	e.	31	se.	22	12	12	6	4.8	0.0	0.0
Miami	25	124	168	29.99	30.02	+.01	80.5	+0.5	90	9	86	69	1	76	17	74	71	73	0.07	-6.8	5	5,801	e.	19	s.	1	4	14	12	6.4	0.0	0.0
Tampa	35	79	197	29.98	30.01	.00	81.3	+1.1	95	28	91	65	5	72	27	72	69	73	1.47	-5.8	7	6,073	e.	32	se.	21	6	20	4	5.7	0.0	0.0
Titusville	44	5	----	29.97	30.03	----	80.7	----	96	30	91	64	6	71	28	----	----	----	1.38	----	3	----	se.	----	----	----	15	13	2	3.6	0.0	0.0
East Gulf States							**80.2**	**+1.7**										**64**	**1.82**	**-2.9**										**4.0**		
Atlanta	1,173	190	198	28.80	30.01	.00	79.3	+3.3	101	29	90	53	9	69	29	65	58	54	0.39	-3.4	4	5,002	w.	33	w.	30	17	13	0	4.0	0.0	0.0
Macon	370	78	87	29.61	30.00	-.01	81.2	+2.3	104	28	94	53	9	69	35	68	61	55	0.79	-3.2	5	3,450	s.	20	sw.	7	11	14	5	4.4	0.0	0.0
Thomasville	273	49	103	29.72	30.01	+.01	81.2	+1.7	103	29	93	58	10	69	34	69	64	63	2.06	-3.4	4	4,129	sw.	30	ne.	29	12	16	2	4.1	0.0	0.0
Apalachicola	36	11	51	29.98	30.02	----	79.2	----	96	29	87	62	9	72	23	73	70	75	3.15	-2.4	5	4,694	w.	36	e.	25	20	10	0	2.4	0.0	0.0
Pensacola	56	149	185	29.96	30.02	+.03	79.0	-0.3	93	25	85	64	1	73	19	71	68	72	1.53	-3.2	3	6,760	sw.	36	e.	25	9	16	5	4.8	0.0	0.0
Anniston	741	9	57	----	----	----	78.4	+3.4	104	28	89	46	9	64	40	----	----	----	2.03	----	6	2,150	se.	15	ne.	19	17	9	4	----	0.0	0.0
Birmingham	700	11	48	29.27	30.02	+.03	80.8	+2.9	106	29	94	52	2	68	33	67	61	59	0.47	-4.0	4	2,788	n.	21	se.	25	17	10	3	3.3	0.0	0.0
Mobile	57	125	161	29.96	30.02	+.03	80.4	+0.1	98	29	90	60	2	71	27	71	68	72	0.65	-4.8	5	4,798	sw.	25	w.	16	10	14	6	4.7	0.0	0.0
Montgomery	223	100	112	29.77	30.01	+.01	81.8	+2.2	100	29	93	58	9	71	31	68	62	56	1.61	-2.2	6	3,581	sw.	27	n.	29	10	16	4	4.4	0.0	0.0
Corinth	469	6	----	----	----	----	80.5	----	105	28	94	49	2	67	40	----	----	----	2.31	----	7	----	se.	----	----	----	15	14	1	----	0.0	0.0
Meridian	375	87	95	29.63	30.01	+.03	79.2	+1.1	101	30	92	53	2	67	35	68	65	62	3.47	-1.1	4	2,762	sw.	25	w.	13	14	13	3	4.0	0.0	0.0
Vicksburg	247	65	73	29.76	30.04	+.07	79.8	+0.8	97	29	90	60	1	69	28	70	66	68	3.30	-0.7	7	3,365	s.	29	sw.	30	18	12	0	3.0	0.0	0.0
New Orleans	53	76	84	29.96	30.01	+.03	81.3	+0.7	95	29	89	68	5	73	20	72	69	70	2.56	+3.3	10	3,185	se.	30	se.	30	9	17	4	4.7	0.0	0.0
West Gulf States							**80.4**	**+0.9**										**71**	**2.26**	**-1.0**										**4.1**		
Shreveport	249	77	93	29.73	29.99	+.03	81.6	+0.9	100	30	92	61	1	71	25	71	66	66	1.28	-2.2	5	3,334	s.	22	sw.	13	19	7	4	3.4	0.0	0.0
Bentonville	1,303	11	44	28.59	29.95	+.01	75.8	+1.7	95	30	86	45	1	65	31	----	----	----	3.01	----	7	2,636	s.	17	s.	11	27	3	0	----	0.0	0.0
Fort Smith	457	79	94	29.48	29.95	+.01	79.7	+2.2	100	30	90	54	1	69	29	70	66	65	1.57	-2.2	7	4,081	e.	32	n.	2	14	14	2	3.9	0.0	0.0
Little Rock	357	136	153	29.62	29.99	+.03	80.1	+2.7	102	30	93	57	1	70	26	69	64	63	2.76	-1.0	8	4,549	sw.	30	nw.	6	17	5	8	4.5	0.0	0.0
Austin	605	136	148	29.33	29.96	----	82.0	+0.8	97	16	93	55	1	71	32	72	68	70	2.63	+0.2	9	4,834	se.	35	s.	21	8	18	4	5.0	0.0	0.0
Brownsville	57	83	100	29.88	29.94	----	81.1	-1.3	92	16	88	68	26	74	18	74	70	81	1.02	-1.8	5	6,936	se.	25	ne.	18	9	18	3	4.5	0.0	0.0
Corpus Christi	20	11	78	29.95	29.97	+.06	81.0	0.0	93	16	86	66	1	76	17	75	74	84	8.36	+5.8	8	8,248	se.	36	ne.	27	10	16	4	4.4	0.0	0.0
Dallas	512	220	227	29.42	29.96	----	81.2	----	97	26	91	62	1	72	27	----	----	----	0.94	-3.0	5	7,190	se.	44	ne.	12	14	13	3	3.2	0.0	0.0
Fort Worth	670	106	114	29.24	29.94	+.02	81.4	+1.5	96	25	91	57	1	71	29	70	65	61	2.43	-0.9	8	6,023	se.	29	e.	12	13	13	4	4.6	0.0	0.0
Galveston	54	106	114	29.96	30.02	+.07	80.5	-0.2	89	25	84	71	1	77	14	74	72	79	1.74	-2.6	4	6,930	se.	20	w.	26	13	14	3	3.6	0.0	0.0
Houston	138	292	314	29.85	29.99	----	81.6	+0.2	97	16	90	64	1	73	23	----	----	----	0.61	-4.0	7	7,059	se.	33	se.	26	12	16	2	4.1	0.0	0.0
Palestine	510	64	72	29.46	29.98	+.04	80.8	+1.8	96	25	91	61	1	71	26	71	67	68	0.97	-2.7	4	4,510	s.	25	nw.	16	12	13	4	4.3	0.0	0.0
Port Arthur	34	58	66	29.97	30.01	----	81.5	----	94	25	88	64	1	74	20	74	71	75	0.88	----	3	4,588	s.	20	e.	26	20	8	2	3.0	0.0	0.0
San Antonio	693	242	301	29.23	29.94	+.04	81.2	+0.2	96	13	91	63	1	71	24	71	66	67	3.10	+0.6	7	7,171	e.	40	ne.	26	8	18	4	4.7	0.0	0.0
Taylor	571	38	51	29.40	30.00	+.08	81.6	+1.6	98	16	93	55	1	70	34	----	----	----	2.74	+0.7	6	5,290	s.	25	nw.	16	18	11	1	3.7	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, June, 1931*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Ohio Valley and Tennessee							**74.8**	**+2.0**										**65**	**3.13**	**-0.8**										**5.0**		
Chattanooga	762	190	215	29.20	29.99	-0.01	78.6	+3.2	101	28	91	52	9	66	34	65	58	54	0.29	-3.9	4	4,045	sw.	29	ne.	25	13	13	4	4.4	0.0	0.0
Knoxville	995	102	111	28.98	30.01	+.01	77.2	+3.2	101	27	90	50	9	65	33	65	59	59	1.50	-2.6	6	3,367	n.	27	sw.	7	9	19	2	4.6	0.0	0.0
Memphis	399	76	97	29.58	29.99	+.02	80.6	+3.0	101	29	90	56	1	71	26	68	62	58	1.09	-2.5	7	4,347	sw.	40	sw.	7	16	11	3	3.7	0.0	0.0
Nashville	546	168	191	29.46	30.03	+.04	77.7	+2.1	100	29	89	51	9	66	32	67	62	63	2.31	-1.7	7	4,461	nw.	48	n.	15	12	14	4	4.2	0.0	0.0
Lexington	989	193	230	29.00	30.04	+.04	74.8	+2.6	96	28	85	49	1	65	29				1.83	-2.2	9	6,548	sw.	39	nw.	20	12	16	2	3.8	0.0	0.0
Louisville	525	188	234	29.45	30.02	+.04	76.0	+1.3	99	28	86	50	1	66	27	67	63	68	3.14	-0.7	10	4,790	s.	63	nw.	29	6	16	8	5.4	0.0	0.0
Evansville	431	76	116	29.54	30.00	+.03	77.9	+2.8	101	29	88	49	1	67	25	68	64	65	3.55	-0.5	10	4,499	s.	39	sw.	12	11	18	1	4.3	0.0	0.0
Indianapolis	822	194	230	29.12	29.99	+.02	75.0	+3.4	98	28	85	47	1	66	24	65	59	61	2.20	-1.4	9	5,651	s.	34	w.	7	9	10	11	5.7	0.0	0.0
Royal Center	736	11	55	29.20	29.99		72.2		96	28	83	41	1	62	30				8.97	+5.4	10	5,004	s.	30	e.	29	8	6	16	6.1	0.0	0.0
Terre Haute	575	96	129	29.38	29.98		75.8		101	28	86	44	1	65	30	67	62	67	3.74	-0.2	10	4,589	s.	42	n.	22	12	6	12	5.4	0.0	0.0
Cincinnati	627	11	51	29.35	30.01	+.02	73.9	+2.7	99	27	85	46	9	63	33	66	61	69	3.30	-0.4	13	3,027	sw.	26	nw.	7	8	12	10	5.6	0.0	0.0
Columbus	822	216	230	29.15	30.01	+.02	72.5	+1.6	95	28	82	46	1	63	29	63	58	64	2.30	-1.0	7	5,097	s.	43	w.	7	6	15	9	5.6	0.0	0.0
Dayton	899	137	173	29.06	30.00		74.0	+2.6	98	28	84	46	9	64	28	64	59	63	2.90	-0.9	11	4,011	sw.	35	sw.	6	5	21	4	5.5	0.0	0.0
Elkins	1,947	59	67	28.03	30.04	+.04	66.4	-0.5	92	20	79	39	10	54	39	60	57	78	3.09	-2.0	13	2,452	nw.	31	nw.	26	10	10	10	5.5	0.0	0.0
Parkersburg	637	77	82	29.38	30.03	+.03	72.5	+1.1	97	20	84	46	10	61	35	64	59	68	4.18	+0.2	11	2,536	nw.	30	n.	26	8	12	10	5.8	0.0	0.0
Pittsburgh	842	353	410	29.12	30.00	+.01	70.0	-0.7	93	20	81	47	2	59	29	64	61	75	5.72	+1.9	10	4,740	n.	45	w.	20	7	16	7	5.2	0.0	0.0
Lower Lake Region							**67.6**	**+0.9**										**69**	**2.63**	**-0.7**										**4.9**		
Buffalo	767	247	280	29.17	29.99	+.02	65.9	+1.5	90	29	74	47	9	58	30	58	54	70	2.46	-0.4	8	7,712	sw.	42	nw.	25	13	10	7	4.6	0.0	0.0
Canton	448	10	61	29.49	29.95		63.8	-2.0	90	30	75	41	22	52	32				2.67	-0.6	12	4,435	sw.	24	sw.	19	10	11	9	5.1	0.0	0.0
Ithaca	836	74	100	29.09	29.98		65.8	-0.4	98	30	78	42	2	54	41	59	55	68	1.75	-1.8	10	4,913	nw.	29	sw.	20	9	14	7	5.6	0.0	0.0
Oswego	335	71	85	29.61	29.98	+.01	63.5	-1.3	93	20	72	47	2	55	30	58	54	71	2.16	-1.1	10	4,500	w.	18	sw.	20	9	10	11	5.4	0.0	0.0
Rochester	523	86	102	29.44	30.00	+.03	67.3	+1.2	93	20	77	48	2	58	29	59	54	64	2.35	-0.6	8	4,526	sw.	22	sw.	19	12	12	6	4.4	0.0	0.0
Syracuse	596	65	79	29.36	30.00	+.03	66.8	-0.1	96	20	77	45	2	57	33				1.15	-2.7	9	4,011	nw.	23	w.	20	14	10	6	4.2	0.0	0.0
Erie	714	130	166	29.24	30.00	+.02	67.8	+1.6	92	20	76	46	2	60	28	62	59	75	1.76	-1.6	8	6,072	nw.	34	nw.	6	15	10	5	4.0	0.0	0.0
Cleveland	762	267	337	29.19	30.00	+.02	68.6	+1.5	93	25	76	50	1	61	29	61	56	67	3.51	+0.4	8	6,350	n.	56	n.	26	9	13	8	5.4	0.0	0.0
Sandusky	629	5	67	29.34	30.01	+.03	69.8	+1.0	96	25	79	45	2	60	34				3.59	+0.1	11	4,125	e.	32	nw.	20	6	15	9	6.0	0.0	0.0
Toledo	628	208	243	29.33	30.00	+.03	70.4	+1.7	98	25	79	47	1	62	32	62	58	67	4.85	+1.5	11	6,682	e.	35	w.	20	9	14	7	4.6	0.0	0.0
Fort Wayne	856	100	119	29.09	30.00		72.1	+3.6	95	28	82	45	9	62	28	64	60	69	3.04	-0.5	9	5,033	sw.	33	sw.	6	8	15	7	5.2	0.0	0.0
Detroit	730	218	258	29.23	30.02	+.05	69.6	+2.2	98	25	79	46	1	60	34	61	56	67	2.27	-1.3	9	5,168	sw.	35	sw.	20	11	14	5	4.5	0.0	0.0
Upper Lake Region							**65.5**	**+3.1**										**73**	**3.19**	**0.0**										**5.7**		
Alpena	609	13	92	29.34	30.01	+.05	61.6	+1.2	99	30	70	38	1	53	32	57	53	75	2.90	-0.4	11	6,265	se.	45	nw.	19	6	16	8	5.5	0.0	0.0
Escanaba	612	54	60	29.31	29.97	+.03	62.6	+1.9	95	19	70	41	8	55	30	57	54	75	2.63	-0.6	7	6,004	s.	26	n.	7	9	13	8	5.1	0.0	0.0
Grand Haven	632	54	89	29.30	29.97	+.01	67.2	+3.5	89	27	76	40	9	59	26	61	57	71	1.75	-1.2	10	6,288	se.	28	ne.	26	7	9	14	6.4	0.0	0.0
Grand Rapids	707	70	244	29.23	29.98	+.01	71.2	+3.4	99	30	82	43	1	61	29	63	58	65	2.49	-1.0	8	6,438	se.	38	n.	26	6	11	13	6.5	0.0	0.0
Houghton	668	64	99	29.23	29.95	+.01	62.6	+2.6	102	30	73	40	1	52	35				1.81	-1.1	15	5,809	e.	40	w.	19	9	9	12	5.9	0.0	0.0
Lansing	878	6	88	29.06	29.98		68.0	+1.6	95	25	78	41	9	58	33	63	60	78	3.73	+0.2	12	4,437	s.	32	nw.	26	4	19	7	5.6	0.0	0.0
Ludington	637	60	66	29.28	29.98		65.2	+4.7	87	12	72	41	1	58	26	60	57	76	3.52	+0.6	12	5,482	s.	30	n.	26	13	11	6	4.5	0.0	0.0
Marquette	734	77	111	29.16	29.96	+.02	62.6	+3.7	101	29	72	44	16	53	39	57	52	70	4.12	+0.9	11	5,189	s.	33	sw.	9	5	13	12	6.4	0.0	0.0
Port Huron	638	70	120	29.31	30.00	+.03	65.0	+0.8	96	30	74	40	1	56	31	59	55	71	2.27	-0.5	10	5,732	s.	45	w.	20	7	12	11	5.8	0.0	0.0
Sault Sainte Marie	614	11	52	29.31	30.00	+.04	61.6	+3.0	90	30	72	37	1	52	33	56	51	73	3.45	+0.5	12	4,337	se.	24	nw.	8	11	11	8	5.0	0.0	0.0
Chicago	673	7	131	29.26	29.98	+.02	71.8	+4.5	98	28	79	48	1	64	27	64	60	70	4.78	+1.5	8	5,706	s.	30	nw.	22	12	5	13	5.5	0.0	0.0
Green Bay	617	109	141	29.29	29.95	.00	69.2	+4.3	100	30	78	44	8	60	28	62	58	71	3.17	-0.5	11	6,241	s.	27	nw.	26	6	7	17	6.7	0.0	0.0
Milwaukee	681	125	221	29.24	29.96	+.01	69.0	+5.1	100	30	78	46	8	60	32	60	57	70	3.58	+0.2	11	7,333	se.	27	n.	22	8	13	9	5.7	0.0	0.0
Duluth	1,133	5	47	28.76	29.98	+.04	60.0	+2.8	94	29	70	41	1	50	42	55	51	79	4.57	+0.7	12	6,948	ne.	41	w.	19	10	8	12	5.8	0.0	0.0
North Dakota							**68.7**	**+5.5**										**58**	**2.39**	**-1.4**										**5.3**		
Moorhead	940	50	58	28.85	29.85	-.05	69.0	+4.6	102	30	80	37	7	58	34	61	56	64	2.79	-1.3	12	5,090	s.	24	e.	21	7	14	9	5.7	0.0	0.0
Bismarck	1,674	8	57	28.09	29.83	-.04	69.6	+5.9	104	28	82	43	5	58	35	59	52	59	1.66	-1.7	9	5,959	e.	34	e.	21	12	12	6	4.7	0.0	0.0
Devils Lake	1,478	11	44	28.30	29.85	-.03	66.8	+4.9	98	17	79	36	7	54	36	58	51	61	2.54	-1.0	12	6,066	ne.	31	nw.	27	8	12	10	5.8	0.0	0.0
Ellendale	1,457	10	56	28.24	29.84		68.8		102	28	81	40	7	57	36				3.72	-0.9	10	8,206	ne.	48	nw.	21	7	15	8	5.6	0.0	0.0
Grand Forks	833	12	67				67.8		99	30	80	32	7	56	37	60			2.81		13		se.				11	13	6		0.0	0.0
Williston	1,878	41	48	27.89	29.82	-.04	69.3	+6.6	108	16	82	44	7	57	43	56	46	50	1.24	-2.2	7	5,458	se.	37	w.	28	14	10	6	4.5	0.0	0.0
Upper Mississippi Valley							**75.8**	**+5.3**										**66**	**3.96**	**-0.1**										**4.9**		
Minneapolis	918	102	208	28.90	29.86		73.7	+6.2	102	29	84	47	7	64	28				4.78	+0.6	12	7,013	s.	44	nw.	19	7	11	12	6.2	0.0	0.0
St. Paul	837	114	149	29.00	29.89	-.03	73.4	+6.3	101	29	84	47	8	63	34				4.07	-0.1	12	5,445	sw.	43	nw.	19	8	16	6	5.6	0.0	0.0
La Crosse	714	11	48	29.16	29.91	-.02	73.8	+5.5	101	29	84	42	8	63	28	66	62	72	4.40	+0.4	10	2,598	s.	15	nw.	19	8	12	10	5.7	0.0	0.0
Madison	974	70	78	28.92	29.94	.00	71.4	+4.2	99	30	80	46	8	62	29	64	60	70	3.05	-0.7	10	4,674	s.	40	ne.	15	11	8	11	5.2	0.0	0.0
Wausau	1,247	4	62	28.64	29.95		68.8		100	29	80	39	8	58	31				6.34	+2.3	14	3,645	s.	25	se.	3	9	11	10	5.8	0.0	0.0
Charles City	1,015	10	51	28.87	29.91	.00	74.5	+8.0	102	28	86	42	8	63	33	66	62	68	2.41	-2.2	9	4,315	se.	24	nw.	19	14	10	6	4.0	0.0	0.0
Davenport	606	71	79	29.20	29.94	.00	76.5	+6.0	104	30	86	46	8	67	26	66	61	62	2.21	-1.9	6	5,745	sw.	34	sw.	11	12	10	8	4.8	0.0	0.0
Des Moines	861	51	99	29.02	29.90	-.02	76.4	+5.8	99	28	86	46	8	67	30	68	64	67	6.14	+1.4	10	6,010	s.	36	nw.	19	15	9	6	4.6	0.0	0.0
Dubuque	700	81	96	29.20	29.93	.00	75.1	+5.7	103	28	85	45	8	65	31	66	62	67	2.31	-2.0	9	3,648	s.	21	n.	22	12	6	12	5.2	0.0	0.0
Keokuk	614	64	78	29.30	29.96	+.02	76.5	+4.0	102	30	86	48	8	67	24	68	64	67	6.56	+2.4	10	3,911	sw	24	nw.	7	13	8	9	4.2	0.0	0.0
Cairo	358	87	93	29.61	29.98	+.01	79.2	+2.9	100	29	89	54	1	69	25	69	64	64	3.13	-0.7	8	3,903	s.	34	n.	7	7	13	10	5.7	0.0	0.0
Peoria	609	11	45	29.32	29.98	+.03	75.7	+4.8	103	29	86	44	8	65	28	67	63	68	2.20	-1.5	10	3,088	sw.	19	ne.	5	14	11	5	3.8	0.0	0.0
Springfield, Ill	636	5	191	29.30	29.96	+.01	77.4	+5.2	102	30	88	48	8	67	29	67	62	62	3.94	-0.1	11	7,123	s.	36	nw.	7	10	10	10	5.2	0.0	0.0
Hannibal	534	74	109	29.40	29.97	+.02	77.6	+5.1	102	30	87	49	8	68	28				5.72	+1.8	8	4,575	sw.	26	nw.	11	13	11	6	4.1	0.0	0.0
St. Louis	568	265	303	29.37	29.97	+.02	79.6	+4.8	102	29	89	54	1	70	26	68	63	60	1.98	-1.8	6	7,061	s.	39	n.	4	16	13	1	3.5	0.0	0.0
Missouri Valley							**77.5**	**+6.7**										**60**	**2.32**	**-2.0**										**3.6**		
Columbia, Mo.	784	6	84	29.14	29.95	.00	78.0	+5.2	101	30	88	49	8	68	29				1.30	-3.5	7	4,011	s.	23	nw.	7	15	9	6	4.0	0.0	0.0
Kansas City	963	161	181	28.91	29.91	-.01	79.7	+6.1	101	27	89	57	7	70	25	68	62	58	1.50	-3.5	4	4,963	s.	35	sw.	5	19	9	2	3.0	0.0	0.0
St. Joseph	967	11	49	28.90	29.90		78.7		100	30	89	53	8	68	33	68	64	63	2.42	-2.5	6	4,961	sw.	38	nw.	20	19	8	3	2.6	0.0	0.0
Springfield, Mo.	1,324	98	104	28.61	29.98	+.03	76.4	+3.9	97	30	86	52	1	67	28	67	61	62	0.84	-3.8	5	5,931	s.	26	se.	11	27	3	0	1.2	0.0	0.0
Iola	984	11	50	28.91	29.93	-.00	77.8	+3.7	99	27	89	52	1	67	29				3.10	-2.4	5	3,686	s.	17	sw.	10	21	5	4	3.2	0.0	0.0
Topeka	987	92	107				78.2	+4.8	98	28	89	55	1	68	26				2.85	-1.8	4	6,186	sw.	30	ne.	20	18	6	6	3.0	0.0	0.0
Lincoln	1,189	11	81	28.63	29.86	-.04	78.4	+7.0	101	27	89	51	7	67	31	68	63	64	4.42	+0.1	8	6,587	s.	34	n.	20	12	12	6	4.6	0.0	0.0
Omaha	1,105	115	122	28.73	29.88	-.03	79.0	+7.4	102	28	89	51	7	69	30	67	62	61	4.96	+0.4	8	4,565	s.	38	nw.	20	18	6	6	3.3	0.0	0.0
Valentine	2,598	47	54	27.20	29.85	-.01	75.4	+8.5	104	27	89	45	7	62	41	62	55	56	1.31	-1.6	6	6,657	sw.	32	sw.	17	9	14	7	4.8	0.0	0.0
Sioux City	1,135	94	164	28.67	29.84	-.06	77.2	+7.7	102	28	88	46	7	67	31	66	61	62	2.90	-1.1	11	7,892	s.	44	nw.	19	11	9	10	5.1	0.0	0.0
Huron	1,306	59	74	28.48	29.84	-.04	74.6	+8.4	108	28	88	44	7	62	46	63	57	59	1.51	-2.3	10	6,238	s.	27	nw.	14	15	12	3	4.0	0.0	0.0
Pierre	1,572	70	75	28.18	29.80	-.07	76.9	+8.4	110	28	90	50	7	64	37	63	55	52	1.45	-1.5	7	6,488	se.	34	ne.	10	12	16	2	4.0	0.0	0.0
Yankton	1,233	49	57	28.57	29.85	-.04	78.0	+9.1	105	28	89	47	7	67	34				1.63	-2.1	11	4,942	s.	29	se.	3	14	9	7	4.3	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, June, 1931*—Continued

District and station	Elevation of instruments			Pressure			Temperature of the air									Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation			Wind					Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at etd of month
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range				Total	Departure from normal	Days with 0.01 or more	Total movement	Prevailing direction	Maximum velocity: Miles per hour	Maximum velocity: Direction	Maximum velocity: Date						
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Northern Slope							**67.0**	**+5.5**										**52**	**1.46**	**−0.9**										**5.1**		
Billings	3,140	5	----			----	69.4	----	102	16	87	43	25	52	52	----	----	----	0.79	----	7	----	nw.	----	----	----	11	12	7	----	0.0	0.0
Havre	2,505	11	67	27.27	29.86	+0.01	67.4	+5.4	100	26	81	42	5	54	46	53	42	47	1.33	−1.5	9	6,353	sw.	50	sw.	27	6	16	8	5.7	0.0	0.0
Helena	4,124	89	113	25.76	29.87	−.01	63.6	+4.4	94	26	76	41	5	51	46	50	39	48	1.67	−0.7	13	5,190	sw.	32	sw.	16	5	9	16	6.8	9.0	0.0
Kalispell	2,973	48	56	26.88	29.88	−.01	61.0	+3.3	86	7	74	38	30	48	34	49	40	52	1.46	−0.6	11	4,156	nw.	39	sw.	16	3	17	10	6.4	0.0	0.0
Miles City	2,371	48	55	27.36	29.85	.00	72.5	+6.5	107	16	85	45	5	60	41	58	46	47	1.35	−1.3	6	4,257	ne.	34	nw.	30	11	16	3	4.3	0.0	0.0
Rapid City	3,259	50	58	26.53	29.85	.00	72.5	+8.3	105	28	85	50	26	60	39	59	49	48	1.97	−1.4	9	4,990	w.	30	nw.	6	13	13	4	4.2	0.0	0.0
Cheyenne	6,088	84	101	24.04	29.86	+.02	65.6	+5.2	91	28	79	43	7	52	32	52	44	53	1.60	−0.1	10	6,287	w.	39	s.	21	10	14	6	5.1	0.0	0.0
Lander	5,372	60	68	24.63	29.85	.00	66.4	+5.9	92	15	81	41	18	51	42	52	41	48	0.44	−0.7	3	3,554	sw.	37	sw.	26	15	11	4	4.0	0.0	0.0
Sheridan	3,790	10	47	26.03	29.85	----	67.2	----	101	28	83	42	7	52	50	56	47	55	0.91	−1.1	10	2,389	nw.	22	nw.	24	7	17	6	5.1	0.0	0.0
Yellowstone Park	6,241	11	48	----	29.89	+.03	58.1	+2.1	83	25	71	39	12	45	39	----	----	54	1.27	−0.6	8	5,285	sw.	33	sw.	23	4	17	9	----	0.0	0.0
Northe Platte	2,821	11	51	26.99	29.83	−.03	75.5	+8.0	101	27	89	48	7	62	37	64	59	63	2.65	−0.6	9	4,803	s.	29	nw.	1	14	10	6	4.3	0.0	0.0
Middle Slope							**76.7**	**+4.9**										**53**	**1.68**	**−1.6**										**3.7**		
Denver	5,292	106	113	24.74	29.87	+.03	71.3	+5.0	96	28	84	50	11	59	32	55	44	46	0.62	−0.8	10	4,457	s.	25	n.	27	10	15	5	5.0	0.0	0.0
Pueblo	4,685	80	86	25.28	29.84	+.01	74.6	+5.6	98	27	90	49	11	59	38	55	43	42	0.60	−0.8	4	4,350	nw.	26	sw.	30	11	18	1	4.0	0.0	0.0
Concordia	1,392	50	58	28.45	29.88	−.02	79.0	+6.0	100	27	90	55	8	68	33	67	60	57	0.58	−3.8	2	5,507	s.	32	s.	10	19	6	5	3.5	0.0	0.0
Dodge City	2,509	88	100	27.36	29.89	+.02	77.4	+4.9	97	26	90	53	1	65	34	64	57	54	1.46	−1.8	3	9,188	s.	34	sw.	10	22	7	1	2.1	0.0	0.0
Wichita	1,358	139	158	28.50	29.90	−.01	77.8	+3.4	96	27	88	55	1	68	26	67	61	60	5.50	+1.1	7	8,677	s.	33	s.	10	17	8	5	3.5	0.0	0.0
Oklahoma City	1,214	10	47	28.67	29.91	.00	80.6	+4.6	100	27	92	54	1	70	31	68	62	59	1.34	−2.3	5	6,346	s.	25	n.	5	14	12	4	4.2	0.0	0.0
Southern Slope							**79.5**	**+1.6**										**56**	**1.70**	**−0.8**										**4.0**		
Abilene	1,738	10	52	28.15	29.91	+.03	82.1	+2.9	99	11	94	58	1	70	32	67	60	55	1.22	−1.8	3	7,054	s.	34	sw.	12	9	12	9	5.1	0.0	0.0
Amarillo	3,676	10	49	26.26	29.88	+.03	77.8	+5.0	101	19	91	56	10	64	36	62	55	53	0.69	−2.2	4	6,320	se.	26	e.	14	21	8	1	2.8	0.0	0.0
Del Rio	944	64	71	28.91	29.87	+.02	80.8	−2.6	96	16	91	58	1	71	27	71	67	69	3.98	+1.4	7	5,930	se.	32	nw.	9	9	16	5	5.2	0.0	0.0
Roswell	3,566	75	85	26.34	29.85	+.05	77.4	+1.1	101	19	92	55	2	63	42	60	49	46	0.93	−0.7	7	5,251	se.	29	ne.	15	18	11	1	2.9	0.0	0.0
Southern Plateau							**75.6**	**+1.4**										**36**	**0.57**	**+0.2**										**3.0**		
El Paso	3,778	152	175	26.14	29.81	+.06	81.8	+2.2	102	20	95	58	3	69	34	59	43	31	1.34	+0.8	6	5,530	e.	44	sw.	3	21	9	0	2.1	0.0	0.0
Albuquerque	4,972	51	66	25.05	29.79	----	73.3	----	95	26	89	48	10	58	40	55	40	36	0.53	----	4	3,456	sw.	20	e.	15	12	12	6	4.2	0.0	0.0
Santa Fe	7,013	38	53	23.32	29.82	+.01	67.4	+2.6	89	24	80	41	10	54	35	50	35	37	0.85	−0.2	4	3,747	sw.	21	s.	21	11	14	5	4.0	0.0	0.0
Flagstaff	6,907	10	59	23.40	29.84	+.06	59.8	+0.5	86	27	76	35	9	44	42	46	----	50	0.96	----	7	5,524	sw.	25	s.	8	10	12	8	----	0.0	0.0
Phoenix	1,108	10	107	28.64	29.76	+.02	87.0	+2.5	110	26	101	62	9	73	38	61	42	25	0.02	0.0	1	3,780	e.	22	e.	29	20	6	4	2.9	0.0	0.0
Yuma	141	9	54	29.63	29.77	+.03	85.5	+0.8	112	27	101	61	17	70	40	65	51	38	T.	−0.0	0	3,369	w.	17	s.	4	23	7	0	1.6	0.0	0.0
Independence	3,957	6	27	25.88	29.84	+.06	71.8	−0.5	97	24	87	47	6	57	40	52	----	----	0.62	+0.5	2	----	s.	----	----	----	19	7	4	----	0.0	0.0
Middle Plateau							**69.0**	**+3.9**										**34**	**0.37**	**−0.1**										**3.8**		
Reno	4,532	74	81	25.43	29.85	−.01	63.9	+2.9	91	25	79	35	17	48	44	48	36	44	0.40	+0.1	5	4,990	w.	27	w.	14	17	8	5	3.4	0.0	0.0
Tonopah	6,090	12	20	----	----	----	67.0	----	88	24	78	42	17	56	32	48	34	33	0.25	----	3	----	se.	----	----	----				----	----	----
Winnemucca	4,344	18	56	25.56	29.87	−.01	67.0	+4.2	93	25	83	39	17	51	43	49	33	36	0.69	0.0	2	4,770	sw.	27	nw.	27	16	10	4	3.5	0.0	0.0
Modena	5,473	10	43	24.59	29.81	−.01	65.0	+1.7	90	24	82	41	8	48	41	47	30	33	0.18	−0.1	3	8,742	sw.	47	sw.	16	14	12	4	3.7	0.0	0.0
Salt Lake City	4,360	163	203	25.54	29.81	−.04	73.6	+6.2	96	27	86	51	17	62	34	54	38	31	0.33	−0.5	3	5,588	s.	37	ne.	8	11	12	7	4.2	0.0	0.0
Grand Junction	4,602	60	68	25.33	29.83	.00	75.7	+4.3	97	24	89	53	11	62	36	54	35	30	0.26	−0.1	5	4,700	se.	28	s.	28	13	12	5	4.3	0.0	0.0
Northern Plateau							**66.0**	**+2.0**										46	**0.89**	**−0.2**										**5.5**		
Baker	3,471	48	53	26.42	29.97	+.02	59.4	+0.8	91	7	73	35	30	46	43	49	39	54	0.72	−0.6	7	3,287	n.	17	s.	25	7	11	12	6.0	0.0	0.0
Boise	2,739	79	87	27.08	29.89	−.02	68.2	+2.9	96	26	82	42	30	54	41	52	39	42	0.12	−0.8	4	3,306	nw.	22	nw.	15	10	12	8	5.0	0.0	0.0
Lewiston	757	40	48	29.12	29.92	−.02	68.6	+2.0	100	7	82	48	30	55	43	----	----	----	1.48	0.0	9	2,408	e.	21	nw.	1	6	12	12	6.3	0.0	0.0
Pocatello	4,477	60	68	25.43	29.85	−.02	68.6	+6.4	93	25	82	45	18	55	39	51	38	39	0.09	−1.0	2	4,843	se.	41	sw.	16	8	19	3	4.8	0.0	0.0
Spokane	1,929	101	110	27.91	29.93	−.01	63.9	+1.1	95	7	75	43	28	53	39	51	41	50	0.87	−0.4	9	4,144	s.	22	sw.	17	5	13	12	5.9	0.0	0.0
Walla Walla	991	57	65	28.87	29.93	−.03	67.2	+0.7	99	7	78	48	28	56	39	54	43	47	2.01	+0.9	12	2,832	w.	14	w.	2	11	8	11	5.3	0.0	0.0
Yakima	1,076	58	67	28.79	29.93	----	66.2	−0.2	100	7	78	44	30	54	35	53	41	47	0.91	+0.3	6	3,844	nw.	22	nw.	2	13	6	11	5.3	0.0	0.0
North Pacific Coast Region							**59.3**	**+0.9**										**74**	**4.40**	**+0.3**										**6.4**		
North Head	211	11	56	29.80	30.03	+.04	55.8	+1.0	66	5	60	48	4	52	16	53	52	90	6.02	+3.7	19	8,966	n.	55	s.	25	3	10	17	7.3	0.0	0.0
Port Angeles	29	8	53	----	30.04	----	55.1	----	80	5	62	42	2	48	33	----	----	----	3.35	+2.5	16	3,317	sw.	21	w.	1	8	7	15	----	0.0	0.0
Seattle	125	215	250	29.86	29.99	−.01	59.6	+0.6	86	6	67	46	2	52	30	53	48	70	3.35	+2.0	16	5,179	s.	28	w.	26	4	14	12	6.6	0.0	0.0
Tacoma	194	172	201	29.81	30.01	−.02	60.0	+1.3	85	6	68	47	3	52	30	----	----	----	3.84	+2.4	15	4,910	n.	23	w.	26	4	16	10	6.5	0.0	0.0
Tatoosh Island	86	9	53	29.90	30.00	−.02	54.4	+1.4	69	6	58	47	4	50	19	52	50	88	6.99	+3.8	17	6,853	sw.	35	e.	13	6	6	18	7.0	0.0	0.0
Medford	1,329	29	58	28.57	29.96	----	63.7	----	93	5	77	42	3	51	43	53	44	60	3.49	+2.8	9	4,158	nw.	24	nw.	22	12	7	11	5.4	0.0	0.0
Portland, Oreg	153	68	106	29.84	30.00	−.04	63.6	+1.2	91	6	73	47	3	55	32	56	50	68	3.13	+1.6	16	3,296	nw.	20	w.	28	7	6	17	6.8	0.0	0.0
Roseburg	510	75	99	29.46	30.01	−.02	62.2	−0.3	92	5	74	42	29	50	43	54	48	66	5.02	+3.9	9	2,616	n.	22	sw.	25	13	8	9	4.9	0.0	0.0
Middle Pacific Coast Region							**65.9**	**+1.5**										**66**	**0.60**	**+0.3**										**3.7**		
Eureka	62	73	89	30.00	30.07	+.02	57.3	+3.0	68	15	62	48	12	52	18	54	51	83	1.33	+0.6	6	4,558	n.	27	nw.	29	12	8	10	5.2	0.0	0.0
Red Bluff	330	5	58	29.53	29.88	.00	75.0	+0.2	101	25	88	55	2	62	35	59	46	43	0.99	+0.5	3	4,327	s.	24	se.	5	15	11	4	3.9	0.0	0.0
Sacramento	69	106	117	29.82	29.90	+.01	69.8	+0.4	100	25	83	50	3	56	37	59	53	62	0.29	+0.1	3	5,961	s.	26	sw.	5	25	3	2	1.6	0.0	0.0
San Francisco	155	208	243	29.80	29.96	.00	62.0	+3.5	84	25	68	52	4	56	24	55	52	74	0.32	+0.1	3	5,753	sw.	28	nw.	27	10	12	8	4.5	0.0	0.0
San Jose	141	12	110	29.83	29.98	----	65.6	+0.6	94	25	77	47	28	54	41	----	----	----	0.07	−0.0	3	4,426	nw.	24	sw.	5	18	9	3	3.1	0.0	0.0
South Pacific Coast Region							**71.0**	**+2.3**										**63**	**0.38**	**+0.3**										**3.5**		
Fresno	327	89	98	29.54	29.89	+.04	73.8	−2.0	103	25	88	54	3	60	34	58	46	46	1.12	+1.0	3	5,991	nw.	23	nw.	13	19	8	3	2.8	0.0	0.0
Los Angeles	338	159	191	29.56	29.92	+.02	70.5	+4.1	96	25	79	57	3	62	28	61	56	66	0.02	−0.1	1	2,963	sw.	17	nw.	25	13	14	3	3.6	0.0	0.0
San Diego	87	62	70	29.83	29.92	.00	68.7	+4.8	96	24	74	59	6	63	27	63	60	78	0.01	0.0	1	3,911	sw.	16	w.	21	15	9	6	4.2	0.0	0.0
West Indies																																
San Juan, P. R	82	9	54	29.90	29.99	----	81.1	+1.4	92	11	86	73	6	76	16	----	----	----	9.45	+4.2	16	6,444	e.	27	n.	12	4	15	11	6.4	0.0	0.0
Panama Canal																																
Balboa Heights	118	6	97	----	[1] 29.84	+.02	80.4	+0.3	91	7	86	73	12	75	18	----	----	[1] 89	7.81	−0.2	22	3,465	nw.	25	nw.	12	0	1	29	8.5	0.0	0.0
Cristobal	36	6	97	----	[1] 29.84	+.01	82.5	+2.1	91	24	88	76	27	77	15	77	76	[1] 83	9.26	−4.4	22	4,187	se.	22	nw.	1	0	5	25	9.0	0.0	0.0
Alaska																																
Fairbanks	455	11	44	[2] 29.31	[2] 29.82	----	56.6	----	82	17	69	32	3	44	36	48	41	63	1.73	----	9	2,991	sw.	20	nw.	11	3	19	8	6.0	1.2	0.0
Juneau	80	11	50	[2] 29.84	[2] 29.93	----	54.7	----	77	16	62	39	1	47	30	49	44	74	5.10	----	14	3,086	s.	15	se.	22	6	9	15	6.8	0.0	0.0
Hawaiian Islands																																
Honolulu	38	86	100	[2] 30.02	[2] 30.06	----	77.6	+1.0	84	9	82	69	8	73	13	70	67	72	0.18	−0.7	8	6,294	e.	24	e.	22	16	13	1	3.8	0.0	0.0

[1] Observations taken bihourly.

[2] Pressure not reduced to mean of 24 hours.

NOTE.—The data for Table 2, not having been received in time from the Canadian Meteorological Service, will be published in the July REVIEW.—*Ed.*

Chart I. Departure (°F) of the Mean Temperature from the Normal, June, 1931

Chart I. Departure (°F) of the Mean Temperature from the Normal, June, 1931

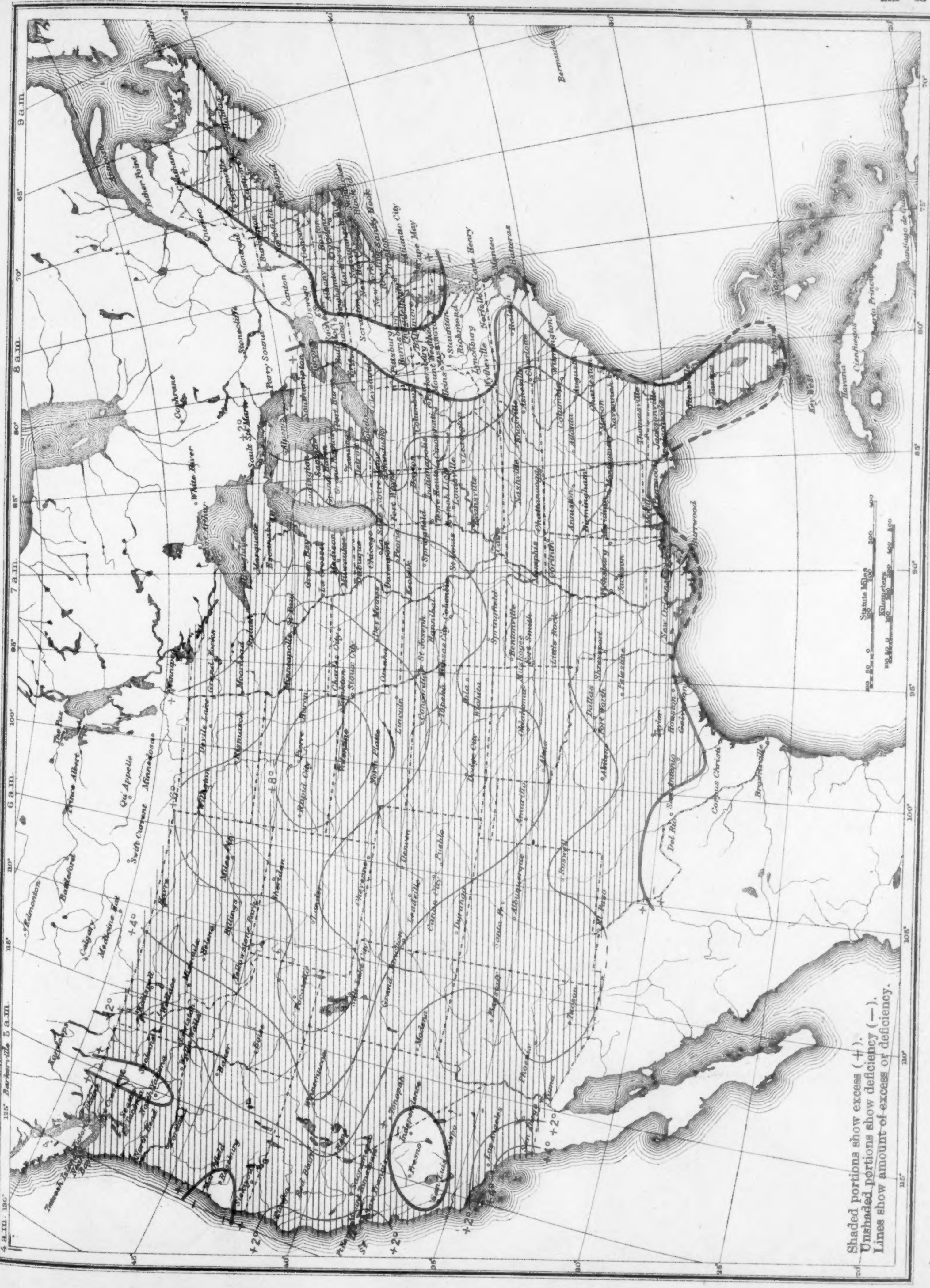
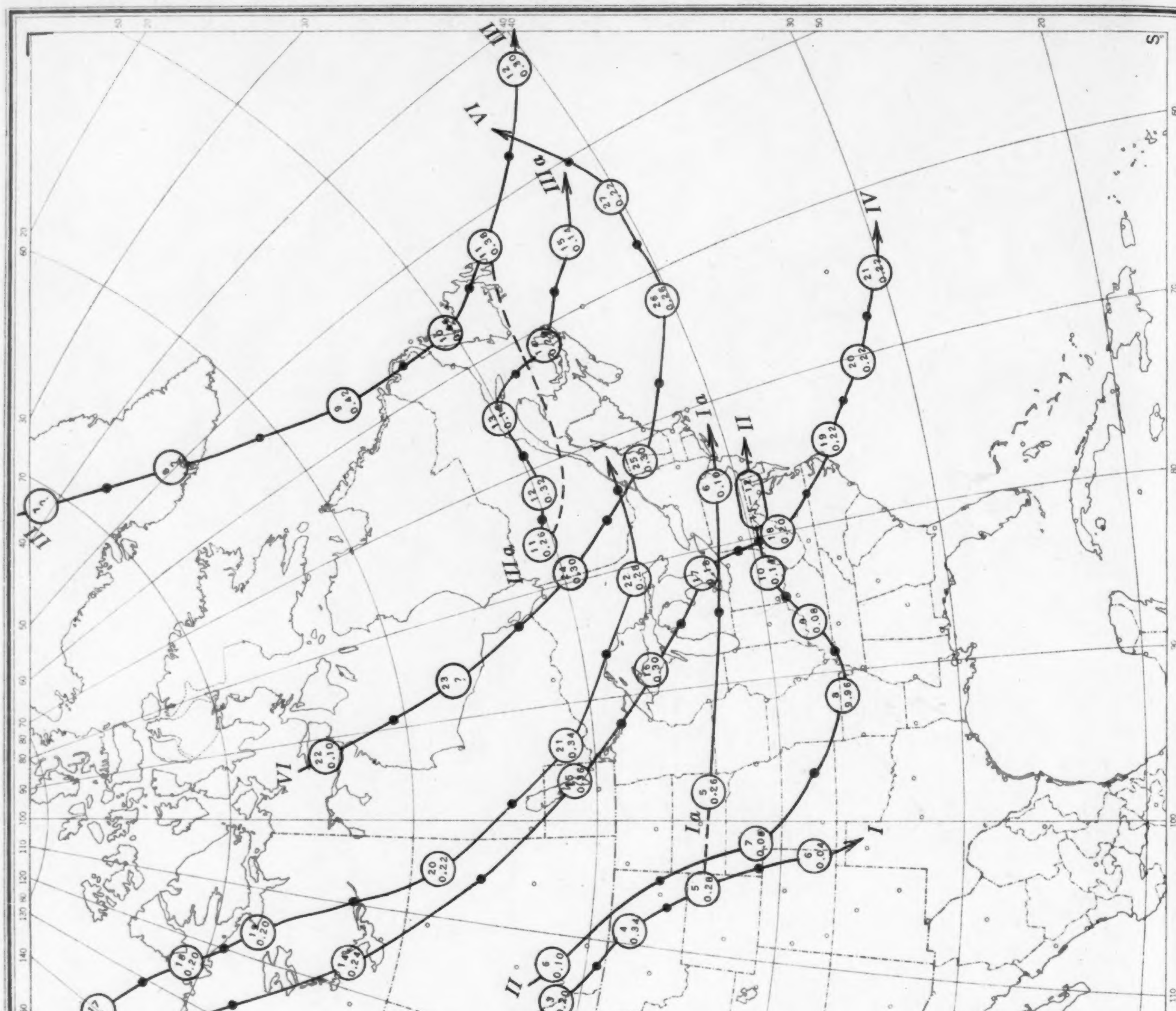


Chart II. Tracks of Centers of Anticyclones, June, 1931. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by G. E. Dunn)



Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

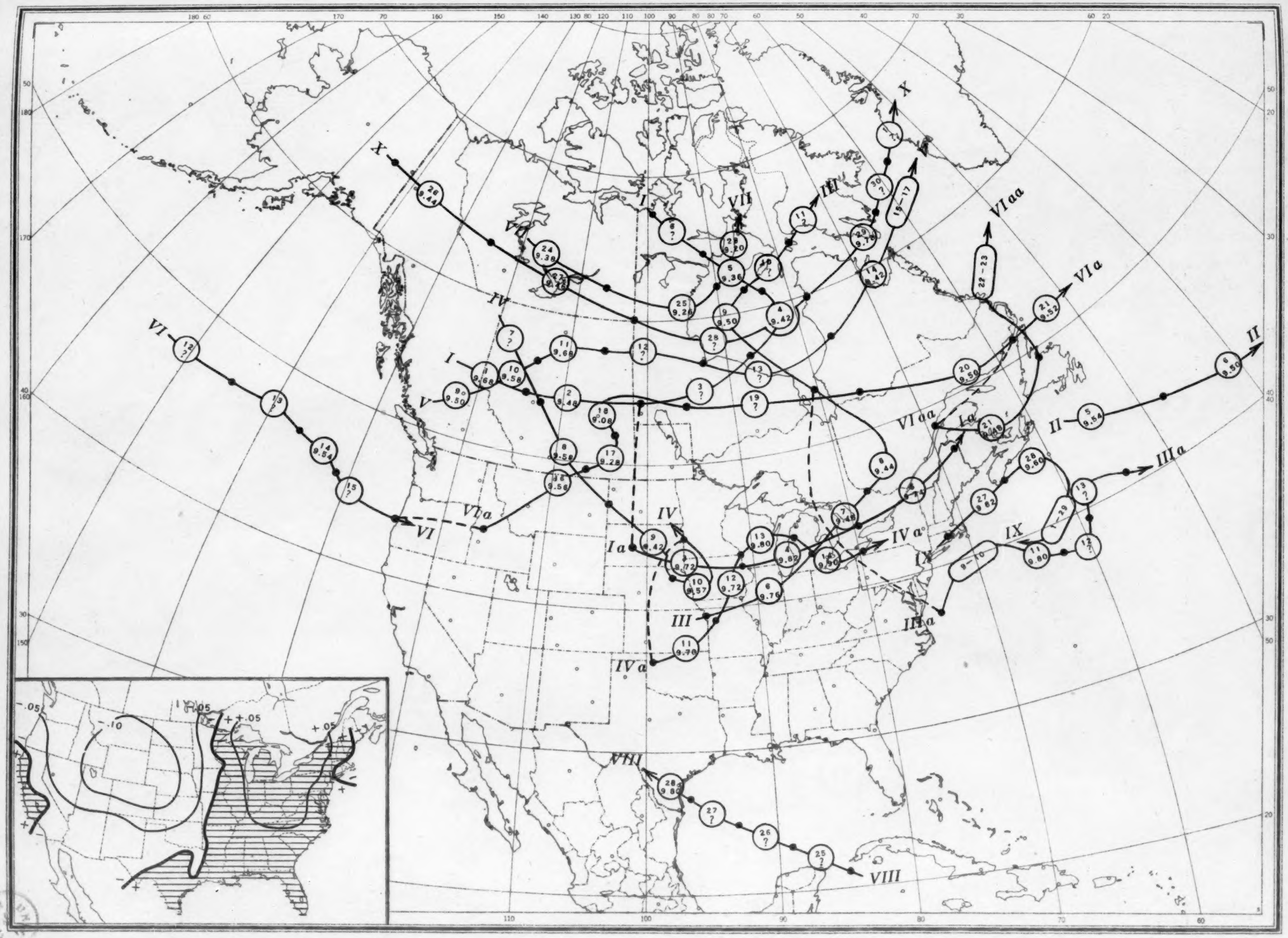
Chart III. Tracks of Centers of Cyclones, June, 1931. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by G. E. Dunn)

Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, June, 1931. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by G. E. Dunn)



Circle indicates position of cyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 8 p. m. (75th meridian time).

Chart IV. Percentage of Clear Sky between Sunrise and Sunset, June, 1931

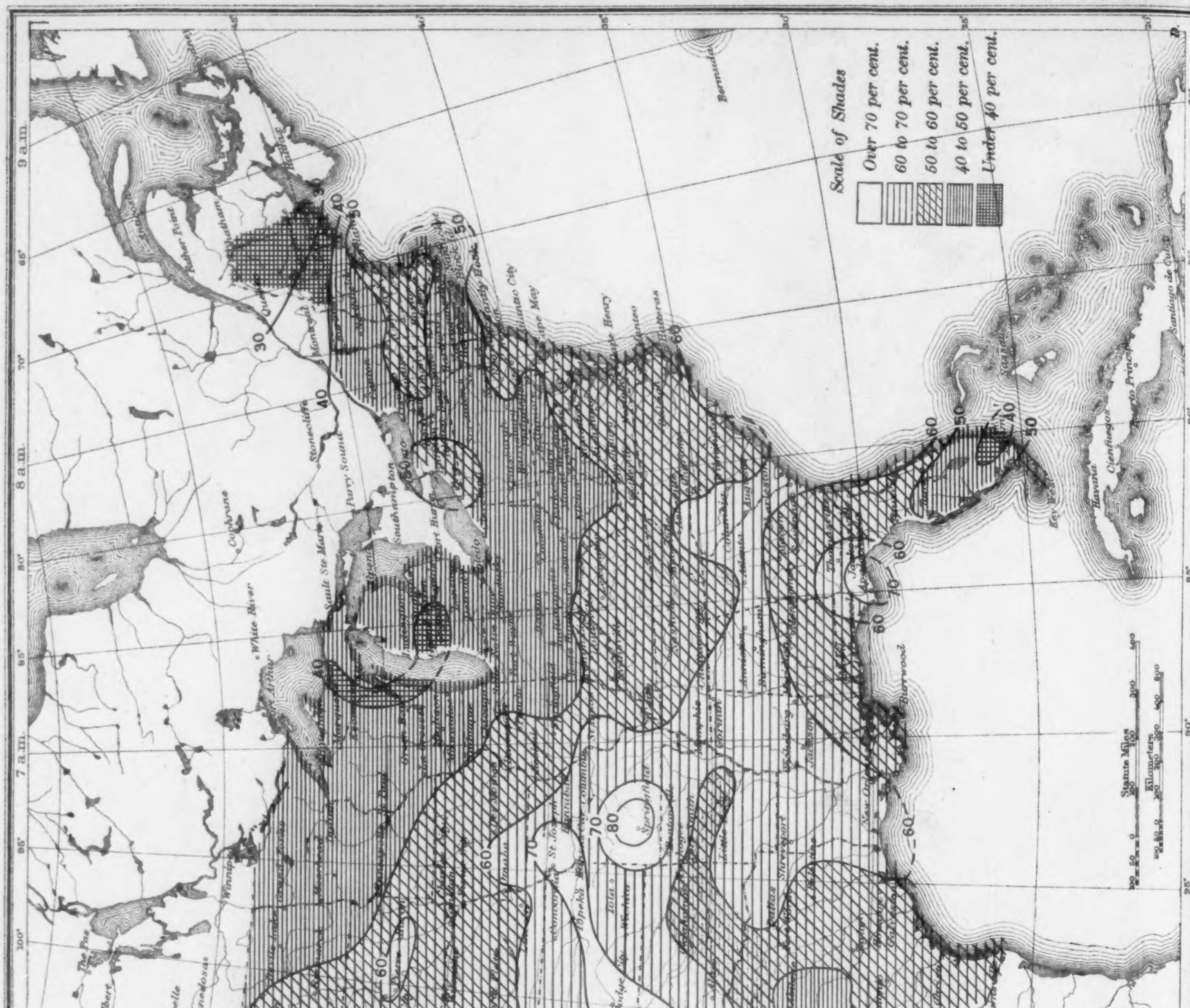


Chart V. Total Precipitation, Inches, June, 1931. (Inset) Departure of Precipitation from Normal

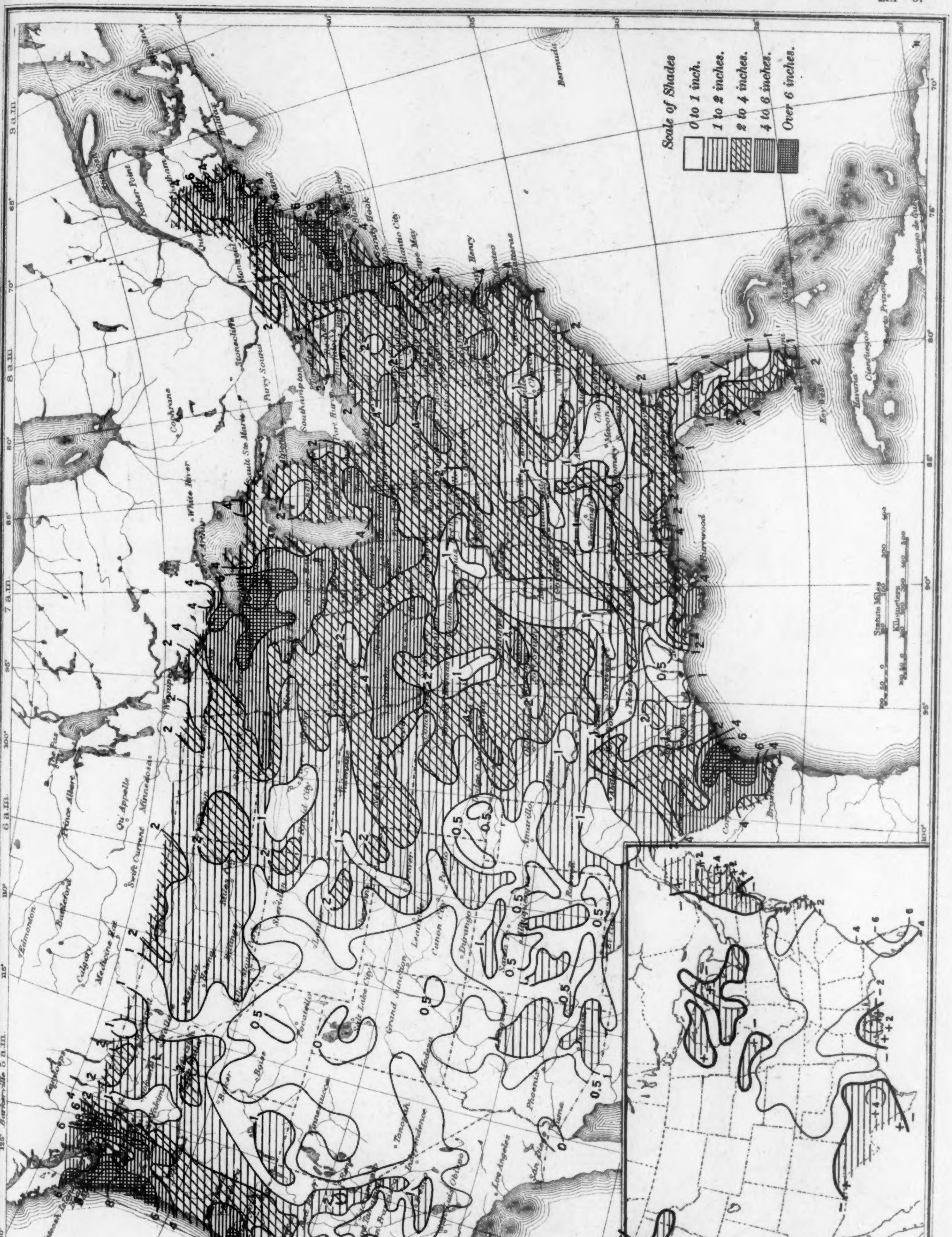


Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, June, 1931

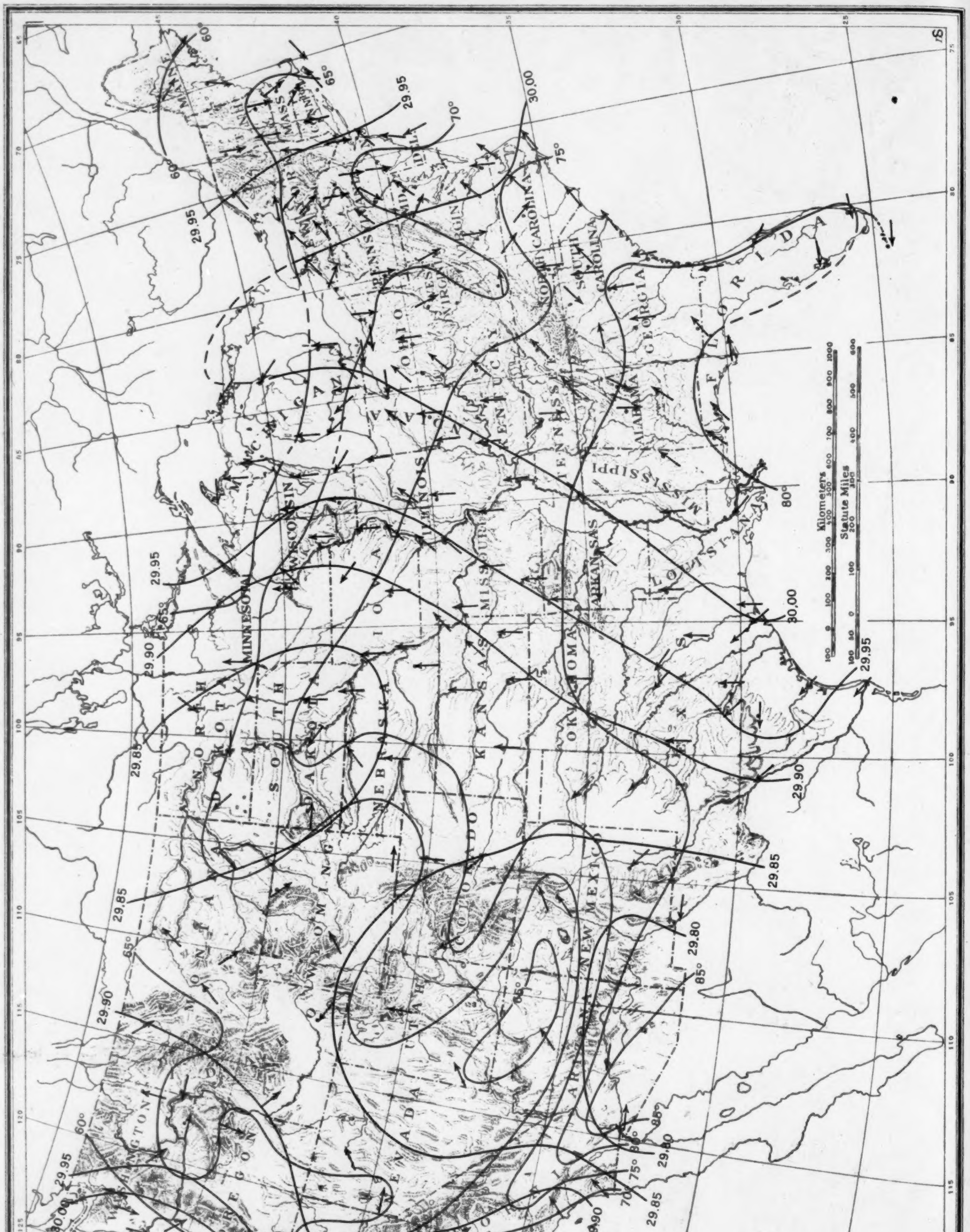


Chart VIII. Weather Map of North Atlantic Ocean, June 23, 1931

(Plotted by F. A. Young)

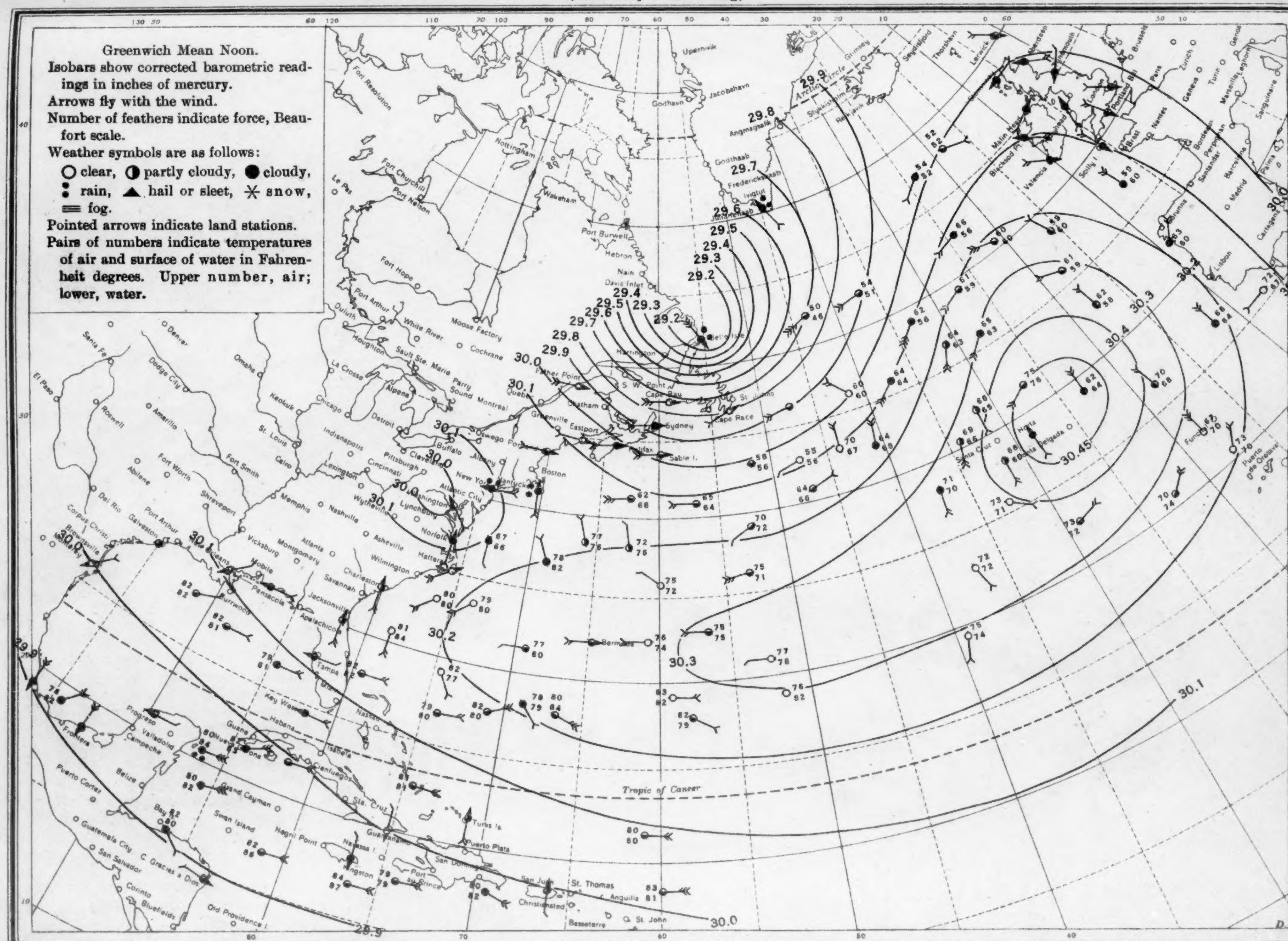


Chart IX. Weather Map of North Atlantic Ocean, June 24, 1931

(Plotted by F. A. Young)

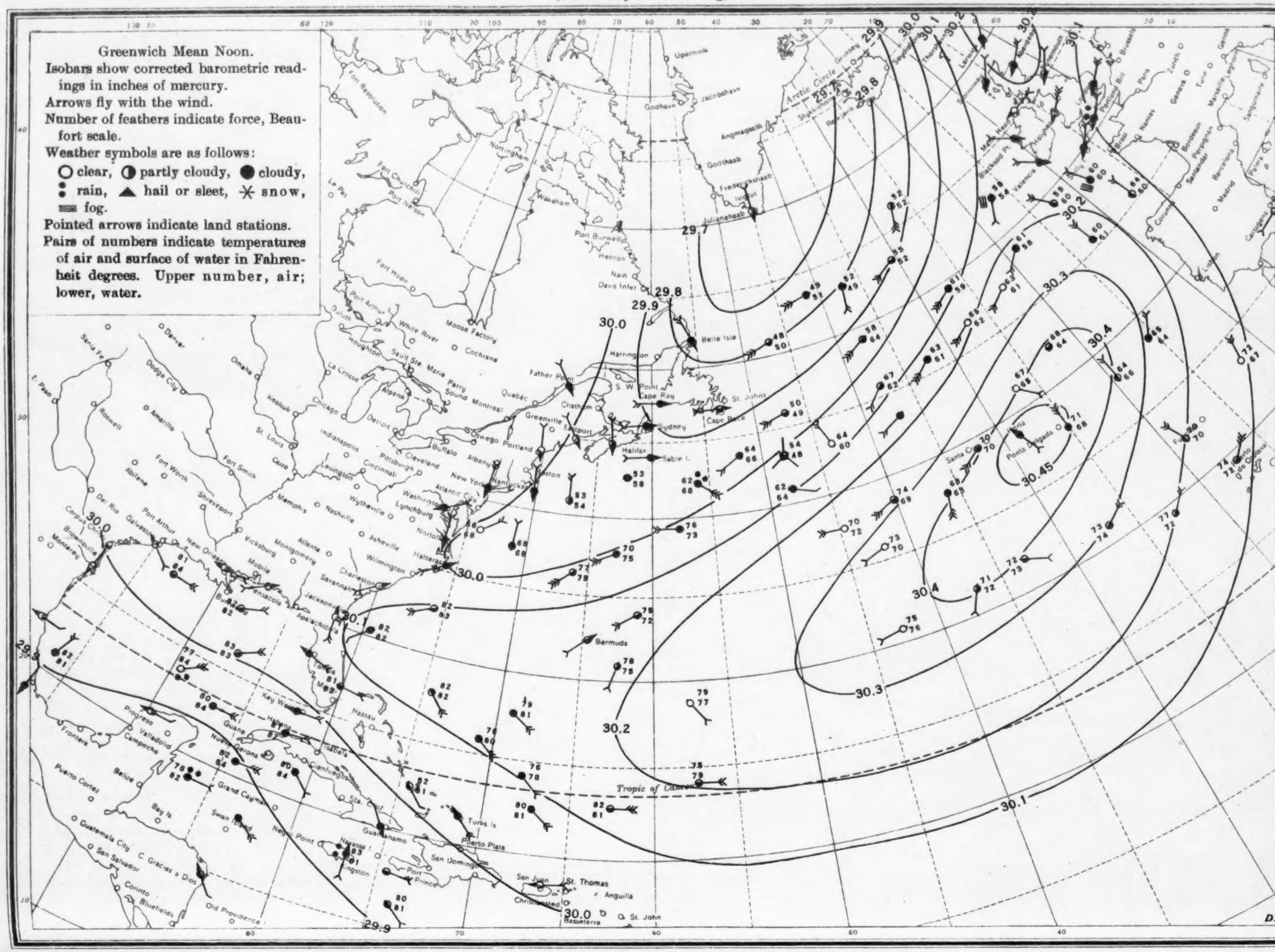


Chart X. Weather Map of North Atlantic Ocean, June 25, 1931
(Plotted by F. A. Young)